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A TEXT-BOOK

OF

BIOLOGY

FOR STUDENTS IN GENERAL, MEDICAL AND TECHNICAL COURSES

BY

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DEDICATED

TO MY ALMA MATER

SYRACUSE UNIVERSITY

FROM WHOM WITH THE PASSING OF THE YEARS I MORE AND MORE
DRAW INSPIRATION FOR MY WORK

PREFACE TO THE FIFTH EDITION.

In this edition the historical development of the Science of Biology furnishes the plan for the first seven chapters with two additional features: first, the scientific method of analyzing biological problems is stressed; and, secondly, the comparative relationships are pointed out.

This form of organizing the work for beginning students has the advantage of starting from the known and gradually leading up to the unknown; of clearly indicating to them how their information should be classified and how to draw conclusions from such a grouping of the facts; and of pointing out the basal relationships in the great group of vertebrates.

It is then an easy step to study the fundamental facts about the life of the unicellular organisms. Here the same methods of study and principles of interpretation are followed.

There is a general agreement in regard to the chief facts suitable for the introductory part of a course in Biology, but difficulties arise as to what shall follow. We have found it convenient to separate the laboratory problems of the second half of the course from the general discussions. The simpler animals and plants afford many examples of the beginning of tissue differentiation, the development of sex, and other basal biological problems. One can follow the origin of organs through the mosses, ferns and to the flowering plants or through hydra, the earthworm, or crayfish to insects or both as time is available. The limits of the book do not allow including more than a few of the forms more frequently used. In such studies one is impressed with the gradual changes that take place as the flower with all of its parts on the one hand or the head of an insect on the other hand, takes form from simpler structures. It is a most significant lesson, and one that follows naturally after the plan employed in the early part of the book.

The theoretical considerations and general discussion are reversed in this edition and much new material added. The writer has tried various plans with his own classes and this one seems to be preferable.

Some may question the value of a chapter on the Scientific Method in a book which is wholly organized on that plan, but while this form of thinking is presented, it needs summarizing and emphasizing for students do not find this phase of the work easy, and it seems to the writer that this is one of the important features that his course offers.

We had come to think that evolution was so widely accepted that it was not necessary to give special attention to the way that it was presented, or to the arguments in substantiation of it, but the propaganda against evolution is of such a nature that we have been impressed with the importance of supplying students with a more complete account than in our former editions.

One who has been teaching Biology for many years has of necessity consulted the chief authorities and kept in touch with current investigation and finds it difficult to recall which papers, books, or men, or which conference has most largely influenced his thought in preparing such a text. Obviously, his more immediate associates play a large part, but of all of these, I am inclined to believe the most credit should go to my own students whose questions and interests have stimulated me to try to satisfy their needs. A number of friends have kindly furnished me with recent facts and new illustrations that do much to give new life to an old theme, and the publishers have made every effort to satisfy my requests.

W. M. S.

Syracuse, N. Y., 1924.

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A TEXT-BOOK OF BIOLOGY.

PART I.

THE FUNDAMENTAL PRINCIPLE OF BIOLOGY AS ILLUSTRATED BY A COMPLEX ANIMAL—THE FROG.

CHAPTER I.

ORGANISM.

THIS book aims to present an introduction to what man has learned about life. The most obvious fact is that this expression can be used in connection with any mass of living substance, that is, we have come to think that the same general principles govern life in man, a tree, or a fly. That such a generalization can be stated at the very outset is an indication of the progress that has been made in our grasp of the basic relationships of living things.

Biology Defined.—With the vast accumulation of information about life in recent years, it has become necessary to introduce a general grouping of our facts, which gives us such terms as Botany, and Zoölogy; the former including the life of plants, and the latter that of animals. This subdivision has a tendency to emphasize the separateness of plants and animals and Lamarck and Treviranus in 1803 attempted to overcome this by coining the term Biology which is a description of the fundamental characteristics common to both, often defined as the *science of living things*. A biologist then is one who devotes himself to the study of life as it is expressed in any and every living thing.

It took man a long time to discover and clearly think out these relationships; and, when one follows the historical development of biology as we do in the early part of this book, it will be noted that

first one phase of life was prominent, then another, until we come to the modern point of view which seeks to give to each its proper place in elucidating the phenomena of living things.

The early students of biology found a multitude of animals and plants, the mere names of which were unrecorded. Today it is believed that there have been more than 1,000,000 different kinds of living things, that lived either in ancient times and are now recorded only in the rocks as fossils, or are present on the earth today.

No one would be so rash as to claim that he knows intimately even a small number of this vast array, but any trained biologist is able to place nearly all of them in the groups upon which scientists have agreed. Just how this classification is worked out is our first problem.

When men began seriously to study animals and plants and to make permanent records of their observations in writings, Latin was the language used as this was the only language common to educated men in all countries. All of the older records and even some of the present day descriptions are in Latin. The earlier descriptions were satisfactory as long as only a few plants and animals were known, but it soon became evident that some definite plan would be necessary. The great Swedish naturalist, Linnaeus, in 1758 devised a method of naming plants and animals that has become a permanent part of the science of biology. His plan was to use two Latin words. The first is a general or generic name that indicates the group to which the individual belongs, its general relations; while the second is a special or specific name that applies to the individual alone and emphasizes its individual differences. For example, the cat-like animals were given the generic name of *Felis*, and all that is necessary in naming these animals is to add to *Felis* a specific name, as *domesticus* for the common cat, or *Felis canadensis* for the Canada lynx. In a similar way the dog-like animals were united under the genus *Canis*, and so there is *Canis lupus*, the wolf; *Canis vulpes*, the fox; or *Canis familiaris*, the common dog. The same method is used in naming plants. Wake Robin is a popular name for all of the Trilliums, but if one desires to designate the common white trillium, he uses Trillium grandiflorum or Trillium erythrocarpum for the painted trillium. When such names have been devised for a specific animal or plant, it is customary to recognize it as a distinct species. Man himself comes within this plan and is thus known as *Homo sapiens*.

Species Defined.—One of the common definitions of a species is that *a species consists of a number of animals that resemble one another so closely that to know one is to know all of the individuals.* For example,

if you are familiar with Canis familiaris or Trillium grandiflorum you would recognize them anywhere. As you extend your studies, you will come to realize that the differences between closely related species are not sharp and that specialists make arbitrary decisions about just

FIG. 1.—Linnaeus at sixty years, 1707–1778. (From Locey's Biology and its Makers.)

Carl von Linné or Linnaeus introduced the method of naming plants and animals that is used at present and is the founder of the modern methods of classification. He confined his studies chiefly to such descriptions of living things as are illustrated in the text by *Rana catesbiana*. He represents the beginning of the scientific study of biology, which was concerned with the general external appearances of organisms, and which is known now as the science of taxonomy.

which one shall be included under a given designation. We shall have occasion to refer to this again under the subject of variations.

These technical names of species in Latin appeal to the beginning student as unnecessary and burdensome, but when one recalls that the well known dictionaries define only about 300,000 words, it is

easily appreciated that some plan is necessary to define the more than three times as many distinct kinds or species of animals and plants already known.

Organism Defined.—The term organism is given to any particle of life which can be described as a species. One of the well known definitions is "*An organic individual is a unitary mass of living substance which under definite vital conditions is capable of self-preservation.*" This definition is so formulated as to include every condition under which living things have come to live, the minute bacteria or the large elephant, the simple worm or the group of individuals in the ant community.

These definitions include all forms of living things, but because many of them are so simple the following, "An organism is composed of organs" does not apply, although it describes and defines correctly the frog as it does all large animals and is the most used and most familiar definition. Whenever this latter definition can be used the animal is complex, consisting of many highly specialized parts, as arms, legs, eyes, ears, taste and touch organs, or root, stem, leaves, flowers. Each of these has a given work to do and is called an organ. Only a few of the organs in the frog have been observed as yet in this course, but others will be worked out later. *An organ is a structure which does a given work for the organism and is itself composed of many distinct parts.*

Phylum Explained.—More fundamental than these species names are the broad groupings of animals and plants. The entire animal and plant kingdom is divided into branches or phyla (*phylum* from the Greek, *phylon*, a tribe) a phylum being a large assemblage of animals or plants all of which possess important structural characters in common and are believed to have had a common origin, such as the phylum *Mollusa* including clams, oysters, snails, devil-fish and the like; or the phylum *Bryophyta* where one finds the liverworts and mosses.

Turning our attention now more directly to the large group of animals known as vertebrates, one finds that Cuvier in 1795 proposed this term as descriptive of the fishes, amphibians, birds and mammals. Invertebrata is used in opposition to vertebrata and includes the vast number of animals that do not have the structural plan of the vertebrates.

Vertebrata Defined.—There are nearly 35,000 distinct species included in the *phylum Vertebrata* all of which have the following structural pattern: (1) There is an internal skeleton, consisting of a series of vertebra terminating anteriorly in a skull; (2) the brain and

spinal cord are located in the dorsal part of the body and protected and supported by this internal skeleton; (3) there are two body cavities, one in the brain and spinal cord, *known as the neurocele*, and the other in the ventral portion of the body termed the *cœlome* and

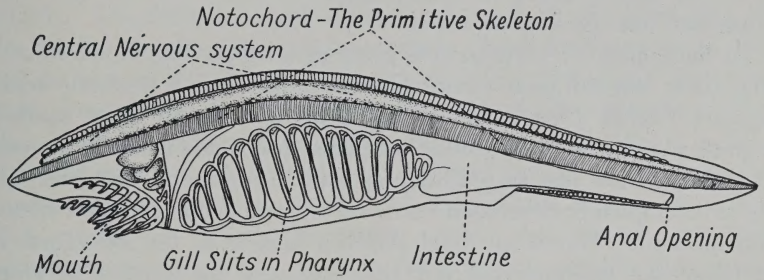

FIG. 2.—Drawing of the larval stage of Amphioxus, to show the primitive plan upon which the body of a vertebrate is organized. The primitive unsegmented skeleton (notochord) supports the central nervous system. Gill slits, posterior to the mouth, occupy a relatively larger space than in the higher vertebrates. The intestinal canal is exceedingly simple. (Drawn from preparation by Hilda Barnes.)

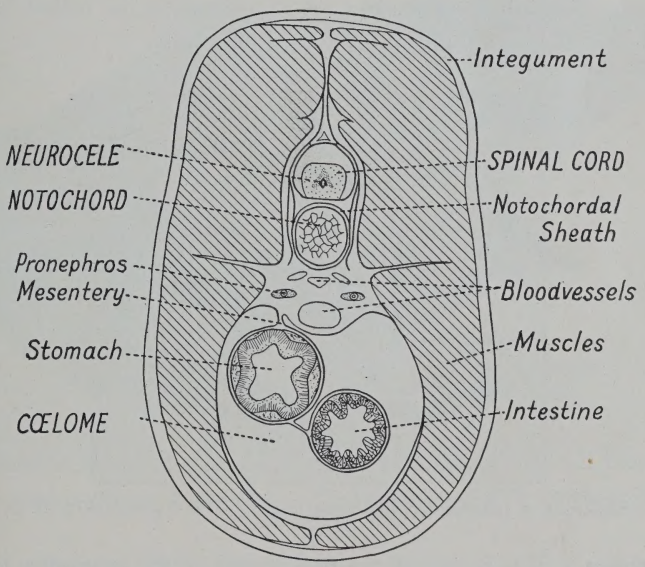

FIG. 3.—Cross-section of an embryo eel, to illustrate the plan of the vertebrate body, the dorsal neurocele and ventral cœlome are the two body cavities. Within the cœlome is shown the bloodvessels, excretory (pronephros), and intestinal canal. The notochord is surrounded by a prominent notochordal sheath. The notochord, shown in Figs. 2 and 3 precedes the vertebral skeleton and should not be confused with this structure. (Drawn from preparation by Charlotte Struthers.)

containing the visceral organs, such as liver, kidneys, intestines, etc.; (4) the pharynx region contains either throughout life or during some period of the embryonic development a number of openings, the gill-slits. All of the vertebrates are built on this general plan and it would be easy to add several additional characteristics but the more important ones have been stated.

In the appendix, Vertebrata is given as a subphylum which means that there is a still more comprehensive term. In our modern classification *Phylum Chordata* is employed because since Cuvier studied animals a number of new groups have been discovered which lack some of the structures just stated, such as skull, a brain and vertebra. In these incompletely developed vertebrates there is one common structure present. This is an axial skeleton known as the *notochord*, a cartilage-like unsegmented rod that supports the central nervous system.

Under the vertebrata as used now are placed a group of very small animals that do not possess even a head and are, therefore, called *Acrania*. Amphioxus is the only representative of the *Acrania*. All of the remaining vertebrates are the *Craniata*, so called because they have a distinct skull built on a common plan.

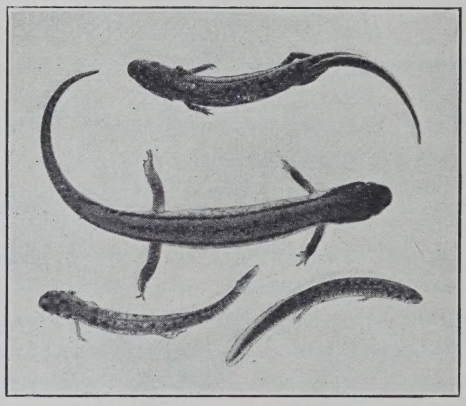

FIG. 4.—Spelerpes, a salamander, adult and larvæ. (Photographed by B. G. Smith.)

Amphibia.—This is one of the five classes of the craniates and the one to which the frog belongs. In all there are 1400 living species of Amphibians distributed among the toads, frogs and salamanders. The salamanders have a tail and the two pairs of legs are of the same length; while the toad and frog are tailless and have the hind legs

much longer than the fore legs. What are the common characteristics which bind salamanders, toads and frogs into a single class, Amphibia?

All modern amphibians have a smooth skin that is kept moist by skin glands. Scales are lacking except in the worm-like *Cœcilians* which are also devoid of limbs so that they are frequently known as *Apoda*. The limbs of amphibians are formed on the same plan as the limbs of turtles, birds, and mammals. Each limb consists of two parts and terminates in five fingers or toes. The single technical term, *Pentadactyl*, is used to describe limbs of this character. The plan of such a structure is wholly different from the fin of a fish. It really represents a distinct advance over the fin as an organ for locomotion, especially on land. All amphibians are cold-blooded. This means that their temperature varies with changes in their immediate surroundings. In this feature they are like fishes and reptiles. Their habit of living both on land and in the water is the reason for the name *Amphibia*–Amphi–both, bios life.

FIG. 5.—*Rana catesbiana*, the bull-frog. (Photograph furnished by American Museum of Natural History.)

Anura.—The Amphibia are roughly divided into the forms with a tail and those without a tail. The tailless amphibians are the toads and frogs, or Anura. There are more than 150 species in this order and our attention must be restricted to the frog. The "true frogs" are classified under the family name of *Ranidæ*, which are distin-

guished from other frogs by slight modifications of parts of the skeleton that require close discrimination. The term *Rana* thus becomes the generic name for frogs, and all that is necessary is to add a name for specific features such as *Rana pipiens,* the leopard frog; *R. catesbiana,* the bull frog; *R. clamatans,* the green frog; *R. sylvatica,* the wood frog. (Figs. 5 and 6.) All of the anura have the same general plan of the body which represents a specialized adaptation. Whenever one comes to study organisms that have undergone such changes, the differences between species are usually minute variations. The salamanders are more like fishes and reveal hardly any special modifications. The Amphibians afford one an opportunity to study a

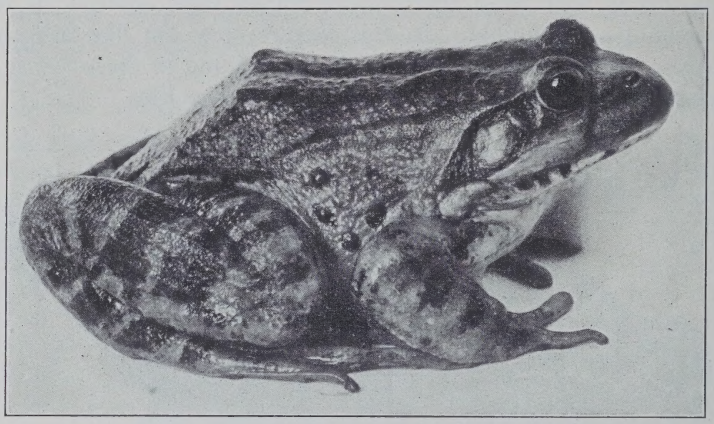

FIG. 6.—*Rana draytonii,* a frog from the Pacific slope. (Photograph furnished by American Museum of Natural History.)

group of animals that are partly aquatic and partly terrestrial in their habits, thus occupying the unique position of a group that were halted in their transition to the fully terrestrial habit. The result is that they reveal structures intermediate between fishes and reptiles, while many of their organs are in an exceedingly simple state of development. For these reasons chiefly, the frog is one of the most familiar animals to all students of zoölogy.

Habits.—The general habits of the group will be illustrated by describing *R. catesbiana.* The amphibia are all aquatic for a part of the time and but few of them (toads) remain away from the water for any length of time. One of the first things that we should learn about an organism is its relationships to all other animals.

In doing this we begin to examine life from one of the many angles known to the modern biologists.

Rana catesbiana is the largest of the North American frogs and is commonly found with a body 6 to 8 inches long when adult. The following technical description illustrates how a taxonomist describes a given species of frog. You should make a similar study in the laboratory: In color the body is green or greenish-brown. The back and sides may be plain in color or may be darkly spotted. Spots distinct or connected. Arms and legs spotted or barred with dark. Under parts white, distinctly or obscurely spotted and mottled with dark color. Throat of male may be yellow. Iris of eye is either golden or reddish-bronze. The femur is about equal in length to the tibia. Head broad and flat; body stout and flat; ear of male larger than eye; ear of female about the size of the eye. Toes broadly webbed; no joints free except the last of the fourth toe. Hind leg 7 to 10 inches long. Sometimes these descriptions of species are spoken of as *Taxonomy* (one of the subdivisions of morphology) and the scientists who specialize in them as *Taxonomists.* The taxonomist is really one who retains his interest in the earliest scientifically developed aspect of biology.

In marked contrast to the methods of the morphologist is the study of what these parts do. Your description in the laboratory of the breathing of the frog is an illustration of applying the scientific method to a rhythmic series of changes in several parts of the body as the life of the frog goes on. In a similar fashion the uses of the legs, tongue, and other parts are considered. This biological method of studying living organisms is one that places its emphasis on the activities and is known as *physiology.* Such a biologist is called a *physiologist* and the field has become so large that there are plant physiologists, animal physiologists and human physiologists. Under this study of activities, the distribution of organisms, their food habits, and daily and seasonal activities may be included. These relations deal with a constantly varying series of changes in the conditions in which frogs live. The successive seasons with their extremes of temperature and moisture necessitate adjustment on the part of the frog. The frog has no influence on these external events. If he can adjust himself, he lives; if not, he dies. The ever onward movement of the cyclic change in Nature sweeps aside everything in its path that is unable to make fitting adjustments. In a more intimate way, day and night require that this change also shall be recognized just as exactingly as summer and winter. This all results in clearly

defined habits in securing food, escaping enemies, and producing offspring.

Haller was the first to direct attention to the importance of studying these general activities but his early conception was very limited. With the accumulation of a larger and larger body of facts, about what animals were doing, special terms were given to this phase of life. It is readily recognized that all such studies involve an analysis of all of the influences outside of the organism—the environment. Seasonal, daily, temperature or atmospheric changes deal with the non-living or inorganic environment. This is often referred to as the *physical environment.* The relations between individuals of the same species, between different species and between animals and plants constitutes a second division of the environment, the *organic* or the influence of living things upon other living things. Today a single term is employed for all of these general activities. It is *Ecology* (oikus–home).

As an example of the use of ecology in connection with the activities of the frog, the following is appropriate. *Rana catesbiana* grows to a large size and may be found commonly with a body 6 inches long, although often secured much larger. This species is quite abundant in northern ponds and streams. In fact, where it is abundant the other frogs are absent, probably because, being smaller, they are eaten by this one. The bull frogs are usually found sitting partly buried in the soft mud or concealed by sticks or grass; when disturbed they dive to the bottom and stir up the mud; then swim back to the edge of the water, usually a foot or two from where they jumped. This habit and the color of their skin is their chief protection from snakes, mud turtles, fish, birds, etc.; they are defenceless unless thus concealed. Wright says that *R. catesbiana* is found along both upland and lowland streams, in clear brooks which feed cold, nearly sphagnous ponds, and also along water-courses laden with such marshy vegetation as lizard-rail, marsh-cress, arrowhead, pickerel-weed and swamp-loosestrife.

It is easy to catch them by dangling a hook variously baited in front of their noses. When this is moved slightly it is usually jumped at, although it may be held still against the nose for some time and be declined. Their food is selected from insects, worms, decaying meat, tadpoles and small frogs. The front leg is used in pushing large objects into the mouth. All food is swallowed immediately. The tongue is the chief organ used in securing small animals. It is thrown out and the passing insect is captured by the sticky secretion on its surface.

The evening croaking of frogs, especially *Rana catesbiana*, suggests that there is a sound-producing organ, and such is the case, for the sound results from forcing air past vocal cords. This voice of the bull frog is a sonorous bass with a good carrying power. "Blood 'n 'ounds," "be drowned," "jug-o-rum" are some of the expressions which are used to imitate the sound. The croaking begins about three weeks after the frog emerges from hibernation. Vocal sacs in the side of the neck of the male act as resonators but are not capable of producing any sounds themselves. By holding a frog under water and gently rubbing it croaking can be produced. The air comes out into the mouth and is then returned to the lungs as if it were just being breathed into the mouth; the air is thus used over and over in sound production.

The activities of the frog are largely regulated by the seasons. Its body temperature is about that of the surrounding medium in which it lives; it therefore varies from season to season. The term cold-blooded is applied to fish, amphibia and reptiles because of their low and varying bodily temperature. During the winter the frog hibernates in the mud below the frost line. The vital activities are greatly lessened, the lungs emptied (cutaneous respiration sufficing), mouth closed, the heart beats feebly and slowly. The energy required to sustain this lowered vitality is taken in part from the muscles and the accumulated fat. *R. catesbiana* is the first of the frogs to come out of hibernation. As soon as the water averages about 64° F. and the air 68° to 75° F., one may expect to find them appearing after their winter sleep. The tadpoles of *R. catesbiana* spend two winters in the larval stage. The legs do not begin to show until the second summer, during July and August. The frogs continue to grow for several years and may increase in size until ten years old. Compare the general habits, environment and tadpoles of the species of frog which you study in the laboratory with *R. catesbiana*. The general activities of the frog in which the whole body is more or less involved may serve as representing the physiological outlook in the time of Haller.

In the same year that Linnaeus announced his bi-nomial plan for naming all species, Haller published his *Elements of Physiology* which has the distinction of marking the beginning of the science of physiology apart from medicine. These general physiological observations which you have made on the frog are valuable and necessary and like the morphological observations furnish you with an incomplete picture of the life of the frog. This incompleteness does not satisfy

you nor did it satisfy the earlier students of plants and animals as they eagerly sought to discover the secret of life. In the next chapter we shall take the next scientific step in the development of biology.

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CHAPTER II.

ORGAN SYSTEMS.

In the first chapter we saw how Linnaeus and Haller by applying a definite method of studying organisms gained true conceptions about all life. Their investigations for the most part have been confirmed by subsequent workers, although many of the interpretations had to be abandoned because their knowledge of living things was mostly external and this gave them an *incomplete set of facts upon which to form a conception of the basic principles of life.* We are now ready to take the next step in the growth of biological knowledge.

This advance consisted in an attempt to analyze the internal parts of an organism, which, like the external parts, are known as organs, and to discover their use. In order to understand the numerous and more intricate problems with which biologists were now confronted, an understanding of the structure of a single plant or animal, however valuable this might be, was found to be inadequate. Men began to compare the internal organs of animals and just as in all great advances, certain men exhibited a deeper insight than others and we have the founder of comparative anatomy, the famous Frenchman, Georges Cuvier, 1766–1832, and the founder of comparative physiology, the equally distinguished German, Johannes Müller, 1801–1858.

The first impression that one gains in opening the cœlome of even as simple a vertebrate as the frog, is the difference in shape, size and color of the several organs. However, if we apply the same careful scrutiny to these parts that was found to be necessary in describing the diagnostic characters of a species, the organs readily fall into groups—solid glands are differentiated from the hollow digestive canal and lungs and this affords an easy classification of the visceral organs.

Digestive Canal.—The digestive organs of the frog consist of a hollow tube or canal and connected with it relatively solid glands. The digestive tube begins with the mouth and ends with the anal opening. The mouth is edged with lip-like folds of skin and many short conical teeth on the upper jaw. The opening itself is rela-

tively large compared with the size of the whole animal; this enables it to eat large tadpoles and small frogs. The teeth are not used in tearing or grinding the food but rather assist in holding it when

FIG. 7.—Johannes Müller, 1801–1858. The most famous physiologist of his time. He introduced the comparative study of physiology and gave special attention to the physiology of organs. His work marks an epoch in the development of the science of biology. (From Locy's Biology and its Makers.)

once seized. The tongue is attached at the tip of the lower jaw and is thrown out by the action of muscles forcing lymph into the tongue. On the roof of the mouth are found the vomerine teeth and beside them the internal nares. Near the angle of each jaw is the Eustachian opening which passes into what corresponds to the middle ear. After the tympanic membrane is removed the solid, single ear bone, the columella, is seen and the short passage into the mouth. The mouth cavity narrows in the posterior region but continues as a tube into a short distensible esophagus. Just in front of this opening is the glottis leading into the lungs. The inner surface of the esoph-

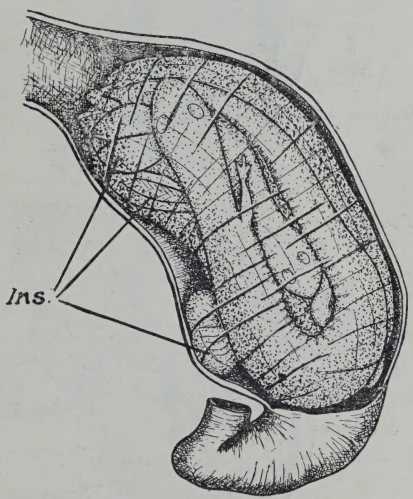

FIG. 8.—Stomach and contents of *Rana clamitans*. *Ins.*, insects. The salamanders belong to the genus Plethodon.

agus is folded and these folds continue into the stomach. There is no sharp boundary between esophagus and stomach. The anterior end of the stomach is wider than the esophagus and known as the cardiac region, and from this region it tapers into the posterior or pyloric end, where a slight constriction, the pyloric valve, separates it from the intestine. Each region of the digestive tube has a characteristic shape; this is particularly true of the stomach, and an expert could readily isolate the correct drawing of a frog's stomach from that of any other vertebrate, such as fish, snake or man. The position, however, which it occupies in the body, and its terminology, such as cardiac and pyloric regions and pyloric valve, are the same

as in all of the vertebrates. Passing from the spindle-shaped stomach the intestine is small, coiled and uniform in diameter until the large intestine is reached, where it becomes much larger. A special name, *cloaca* (sewer) is given to the posterior region of the intestine because of its relation to the urogenital organs, which simply means that this region is used by both the digestive and urogenital organs as a common passage to the exterior.

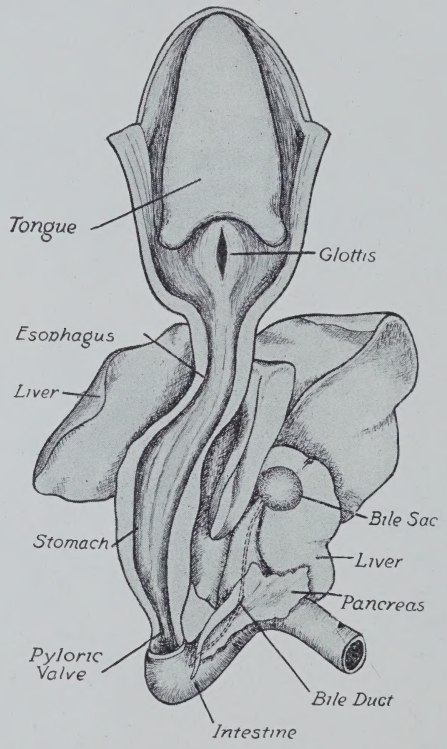

FIG. 9.—Digestive organs drawn from the dorsal surface.

If one compares the digestive canal of the frog with that of the higher vertebrates, all the same regions are present but usually more complex. This is most strikingly shown in the enormous development of the small intestine in the cat or man. With this specialization there has come a certain amount of degeneration resulting in the presence of structures that appear to be useless. The vermiform appendix in man is such an organ and one that frequently must be removed if life is to be preserved; while in the rabbit this structure plays a neces-

sary part in digestion. In making this general comparison it becomes very clear that in all of the vertebrates the canal is entirely closed

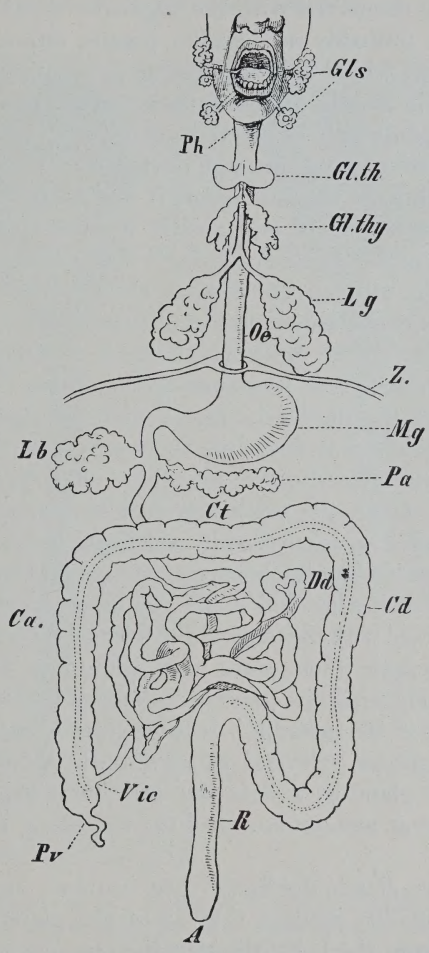

FIG. 10.—Diagram of the alimentary canal of man. *A*, anus; *Ca*, ascending colon; *Cd*, descending colon; *Ct*, transverse colon; *Dd*, small intestine; *Gls*, salivary glands; *Gl. th*, thyroid gland; *Gl. thy*, thymus gland; *Lb*, liver; *Lg*, lungs; *Mg*, stomach; *Oe*, esophagus; *Pa*, pancreas; *Ph*, pharynx; *Pv*, vermiform appendix; *R*, rectum; *Vic*, ileocolic valve; *Z*, diaphragm. (From Wiederscheim.)

except at the ends. Thus it is conceivable that foods might pass entirely through this canal and never actually become a part of the

body of the frog or man. There are no specific openings in the walls of this canal where foods enter the body proper.

Digestive Glands.—This name has been given to several different organs variously connected with the digestive canal. In the frog's mouth there are probably no digestive organs, although an adhesive mucous is present which aids the tongue in capturing insects. Nor are there mouth glands in the aquatic vertebrates as all of their food is seized and quickly swallowed. It is only in the higher vertebrates that digestive glands are well developed. Here they probably first served to lubricate the food before it was swallowed. The mouth glands are all rather small and mostly located either beneath the skin or in the muscles, but having ducts that connect each one with the mouth. (Fig. 10). In the cœlome the two digestive glands, the liver and the pancreas, are similar in all vertebrates.

There are probably no digestive glands in the mouth other than those that secrete the viscid fluid used on the tongue. The large liver, covering most of the digestive organs, and the small pancreas are true digestive glands that discharge their secretions through a single duct into the anterior end of the intestines. The liver which is red, consists of three lobes, the small median lobe being covered by the heart. The whole liver is covered by a delicate membrane that holds it in place. A gall-bladder lies between the right and left lobes (Fig. 9), and appears greenish when full of bile, the liver secretion. The gall-bladder is connected with the lobes of the liver by several minute ducts. These are the hepatic ducts, some of which empty directly into the bile duct. The pinkish-white pancreas is located between the stomach and the first loop of the intestine. It is irregular in shape and through it the bile duct passes. Several pancreatic ducts discharge into the bile duct. Each gland as well as the intestine is held in place by a whitish, translucent membrane called the *mesentery*, that is attached to the back.

These digestive glands discharge their contents into the digestive canal and it is readily realized that all of this glandular generation finally escapes from the body through the anal opening, All of the digestive glands are described, therefore, as producing an external secretion.

Ductless Glands.—The ductless glands on the other hand discharge their products directly into the blood stream and never into the digestive canal. For this reason they are described as the glands of *internal secretion.* In the last ten years particularly, these glands have assumed a very important role in all explanations of the general activities of

animals. The more technical term, *endocrine* (Greek, to separate within) is also employed for these same glands.

In the dissection of the frog, the small red spleen, which you located in the mesentery of the small intestine, is a ductless gland.

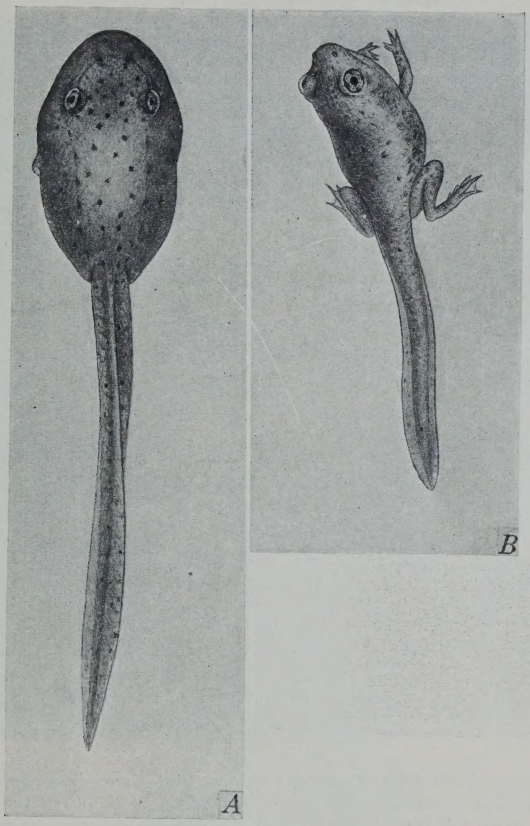

FIG. 11.—Rana clamata larvæ. *A*, control; *B*, animal originally same size and stage of development as *A* twenty-eight days after transplantation with one-half thyroid gland of adult frog. × 2. The effect of thyroid was to hasten the process of metamorphosis of the tadpole into a frog. (From Swengle.)

There are also the thyroid, thymus, adrenal and two connected with the brain, pineal and hypophysis that are also ductless glands. Great importance is attached to the effects of the several ductless glands, and so many investigations are under way that additional facts are continually being revealed.

Respiratory Organs.—The skin and lungs are the important respiratory organs. The lungs are elongated, thin-walled sacs that are capable of great distention and their inner area is about equal to two-thirds of the total area of the skin. When the lungs are empty

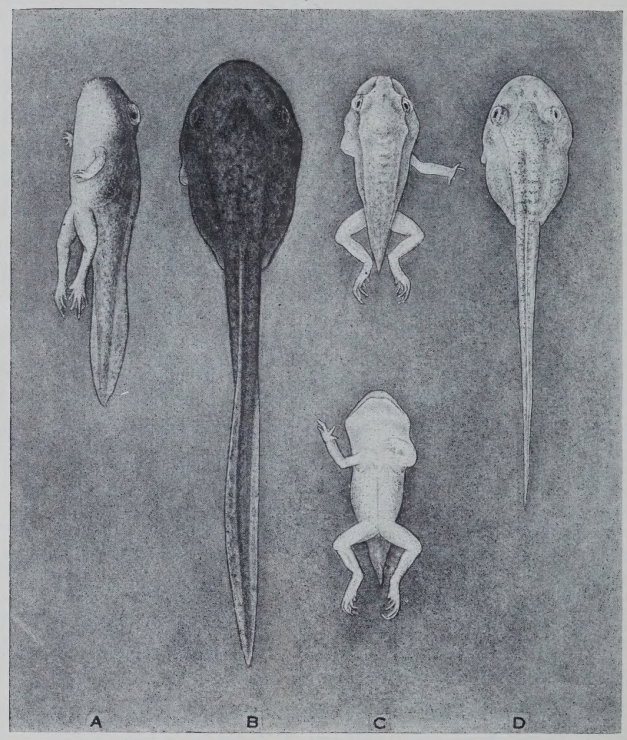

FIG. 12.—Experiments by Swengle to show that there is a specific substance that causes certain changes during metamorphosis. In *A* and *B* the thyroid gland has been removed. The larva shown in *A* was fed iodo-tyrosine fifteen days; while the tadpole *B* was fed tyrosine forty-two days but did not form legs. The pituitary gland was removed from the tadpoles in *C* and *D* with one of the results being that pigment did not form in the skin. The tadpole, *C*, was fed iodo-tyrosine sixteen days; while the one shown in *D* was fed tyrosine forty-two days again showing that the specific chemical, iodo-tyrosine was able to stimulate the changes that result in metamorphosis. (From Swengle.)

of air they become inconspicuous, wrinkled masses. Experiments have shown that the frog can live when deprived of the use of either the skin or the lungs in carrying on the work of respiration. That this work of respiration can be carried on by two very different organs

illustrates well how the frog introduces oxygen into the blood. The oxygen of the air may thus pass through the skin or lungs into the

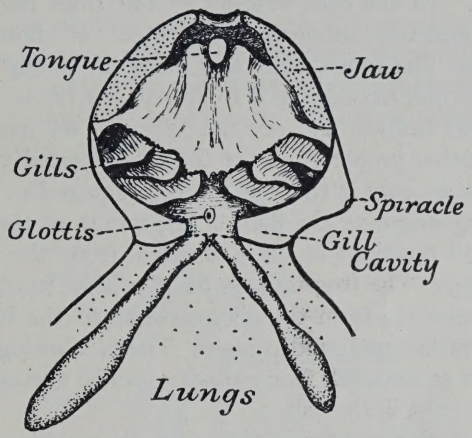

FIG. 13.—Floor of the mouth of tadpole, *Rana clamitans*, to show relation of gills and lungs. The tongue is just beginning to grow backward in the floor of the mouth.

blood. This portion of the process is *external respiration.* The frog breathes by drawing the air into the mouth, which produces an

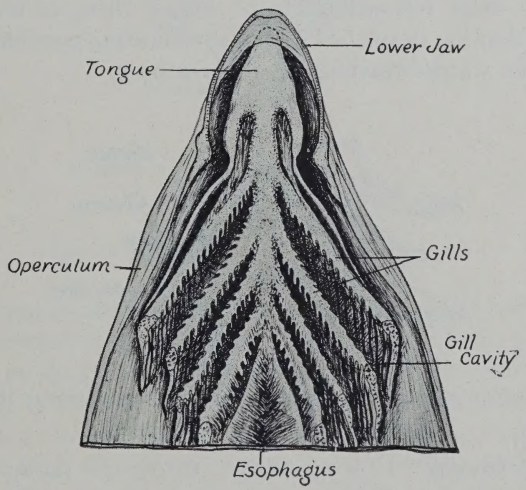

FIG. 14.—Floor of mouth of a fish. Compare Fig. 9. What conclusions can you draw?

oscillation of the throat; then the external nares are closed and the air in the mouth cavity is forced into the lungs. The movements

of the throat do not correspond to the filling and emptying of the lungs. During hibernation in the mud the skin is the chief organ of respiration. In the cold weather of fall frogs remain alive for some days completely submerged in water. It should be clearly understood that the lungs, skin and blood in taking oxygen from the air or water and in carrying it to all parts of the body, are acting in a mechanical fashion and are not carrying on true respiration, because respiration proper is one of the fundamental vital processes and can take place only in the living cells (see page 58).

The water passing over the floor of the mouth of the fish and out through the gill openings is quite distinct from the air-breathing of the adult frog. The frog tadpole has the same mechanism as the fish but the transition from the gill-breathing to the lung-breathing necessitates a rather profound change. The swallowing and respiratory movement of the adult frog require a special nervous mechanism which does not exist in the fish.

The action of the muscles of the trunk in expelling air from the body of the higher animals is a still later modification. The frog cannot take food and air into the mouth at the same time nor can it take air into the lungs while holding the mouth open, as it depends on the muscles in the floor of the mouth to force the air into the lungs. The mere formation of the lungs, then, is not the only mechanism that has developed to make respiration possible as animals changed from water-breathing to air-breathing.

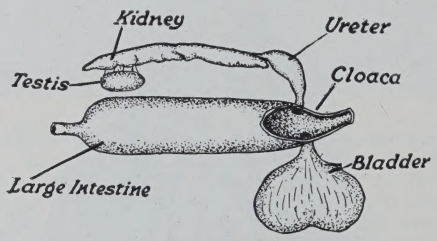

Fig. 15.—Diagram to show the relation of the urogenital organs in the male frog.

Urogenital Organs. It is customary to discuss these two sets of organs under one caption because of their intimate structural connections in the male. The small red kidneys are elongated, flat glands (Figs. 15, 16 and 17), similar in the male and female frog. A short ureter in the female carries the urine from the kidney to the

cloaca. From the cloaca the urea passes by gravity into the ventral bi-lobed bladder (Fig. 15).

On the median ventral surface of each kidney is the yellowish-white adrenal body, a ductless gland. Each kidney is an organ that may be compared to a combined manufacturing and filtering plant. The removal of wastes from the blood is brought about in a twofold manner in the numerous microscopic tubules of which the kidney is composed. (See page 60.)

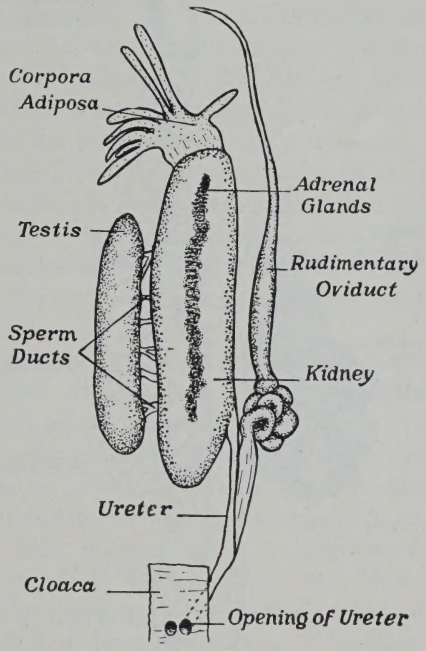

FIG. 16.—Male urogenital organs of the toad.

The ovaries are usually very large, irregular organs surrounded by a thin membrane and attached to the back. These glands have no opening or duct leading from them. When the time arrives for the discharge of the eggs they are set free in the body cavity through many openings in the wall of the ovary. The long coiled oviducts are separate from the ovaries and from each other; each has a wide opening just dorsal to the stomach, into which (so far as we know) the eggs are forced by the general bodily movements. The posterior end of the oviduct is enlarged to act as a receptacle, *uterus*, for the eggs just prior to egg-laying; while most of the anterior portion is gland-

ular, secreting the egg jelly (Fig. 17). The oviduct empties into the cloaca. In the male the parts are more closely united. The small spermary or testis is also a glandular body supported by a mesentery that holds it near the anterior end of the kidney. Through this mesentery pass a number of minute tubes that carry the sperms into the kidney (Fig. 16). After the sperms reach the kidney they pass

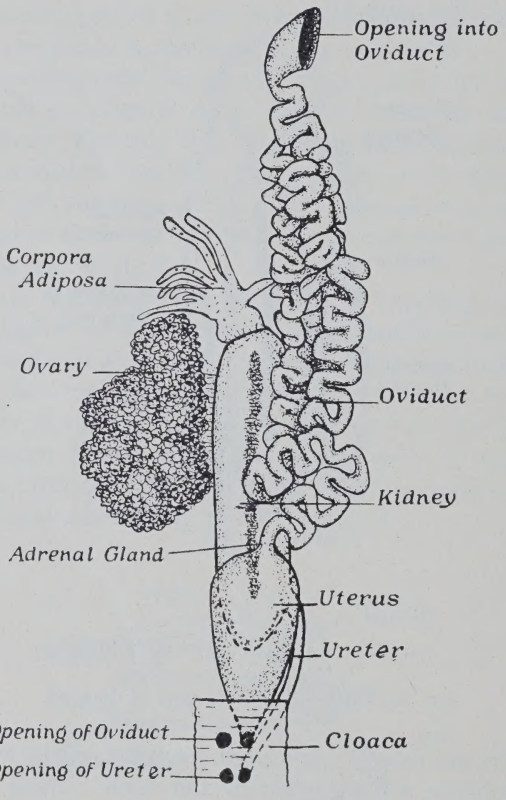

FIG. 17.—Female urogenital organs of toad.

through and escape into the cloaca by using the regular duct of the kidney, the ureter. The ureter of the male becomes enlarged near the posterior end for the reception of sperms. Because this duct carries both urine and sperms it is called the urogenital duct. Critical dissection usually reveals the presence of a small coiled structure just outside of the urogenital duct which can be traced anterior to each

kidney, where it becomes minute (Fig. 16). This is a rudimentary structure, *i. e.*, one that was of use to some ancestor of the frog but not now used. If the large oviducts of the female frog were greatly reduced in size they would look just like these structures in the male frog, which are designated rudimentary oviducts. There are many cases on record of finding in the frog small ovaries variously associated with the spermaries. The rudimentary oviducts and the occasional presence of partly developed ovaries suggest that the ancestors of the frogs were hermaphroditic, *i. e.*, one individual possessed both spermaries and ovaries. Attached to the anterior end of each kidney are the *corpora adiposa*, fat bodies. (Figs. 16 and 17).

It was believed for a long time that the fat stored in these bodies was used to keep the frog alive during hibernation, but it has been observed that they do not decrease in size until the period when the frog begins to grow eggs or sperms. This takes place during early spring, before there is much food available and is an interesting provision that enables the frog to prepare for progeny at a time of the year when there is plenty of water and food for the tadpole development.

Cœlome.—All of these organs are located in a large cavity which is termed the cœlome. It is on the ventral side of the body and is a common cavity in all vertebrates. (Fig. 3.)

Organ System. In any description of a set of organs to which a single name can be given certain intimate relations are implied. While there are many different parts which may have widely different shapes, they all work in harmony to produce some single purpose, as the digestive organs in digesting food, etc. Here each organ does a given part of the whole work. The work is thus done better than if there were no such division into organs. This using of many organs in carrying out a single general work of an organism is characteristic of all complex plants and animals, and results in a system of organs. Each system of organs assumes a given work for the benefit of the organism, so that it is often described under the heading of *physiological division of labor.* This same principle describes accurately the difference between a complex civilization where most people are experts, that is, each does some one thing well, from that of barbarians where each does many things and these but indifferently. In the former case each is dependent upon many others for existence, while in the latter a single family often sustains existence and provides for all of its own wants. The frog would soon die if any of the organs were permanently removed from any of its organs systems. It would be

likewise difficult for us to exist if those persons who supplied us with certain articles ceased to exist.

The organ systems that have been studied in this chapter are the digestive, respiratory and urogenital. The analysis made thus far of the parts of an organism tells us much more than the study of the external parts did, but our information is still incomplete. We must penetrate deeper until we learn the structure of these organs. This is deferred until after the general activities of the several organ systems are presented.

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CHAPTER III.

PHYSIOLOGY OF DIGESTION IN THE FROG.

Need of Food.—There is no record of the time when man first observed that animals require food. Even Aristotle (384–322 B.C.) sought to determine the nature of the materials which plants take up as food and stated that the food of organisms is not simple but composed of various substances. Real progress in solving the problem of what enables life to continue for a given period in all organisms was not attained until certain chemical discoveries of far reaching significance had been made. These center around the discovery of oxygen and the important generalization that a chemical change outside of a living organism and the same change within the living organism are identical.

These discoveries were made between 1770 and 1790 but it was much later before their far-reaching importance was generally accepted. In fact this conception that chemical change within and without the organism was the same, was so revolutionary that its full significance as the only avenue of approach to this obscure problem has but recently been conceded. Today we are in fairly close agreement concerning the production of heat, movement, growth and similar activities in organisms.

The production of heat in the inorganic realm involves the transformation of energy from a potential into a kinetic state. The essential facts of such a change of energy are well understood. The source of the heat whether in coal, wood or electricity is something that man can measure and subject to scientific methods of experimentation. The same is true in connection with the production of heat in animals. The strength of the wind can be measured and so can the movements that take place in organisms be subjected to experimental tests. Growth deals with a more complicated series of relations but requires energy as new parts are produced or a larger body formed.

In these characteristic forms of activity in living things food constitutes the only source of energy. *Food has the power of repairing waste or contributing substance necessary for the growth of the body.* What then is the modern analysis of this food-energy and its relation

to organic activities? As we answer this question, let us constantly keep in mind that energy is not created from time to time but has existed in one form or another since the beginning of the world.

The frog expends energy in three conspicuous ways: (1) In every movement of the body there is an expenditure of energy in the contraction of the muscles. The frog can be made to jump continuously for a time, but soon the jump grows short and it needs a stronger stimulus to cause it; after a little longer time the frog refuses to jump, the muscles are, so far as general observation goes, just the same as when the first jump was made; but after this severe muscular exertion there is a condition of exhaustion until the muscles can be supplied with more food. It is well known that the simple elements which unite to make proteins or carbohydrates do not act as a food when fed to the frog until combined into such complex substances as enable them to be chemically classified as foods. The frog is like all other animals in requiring that its food be ready-made; it has no power to manufacture food out of the raw chemical elements. (2) The need for energy arises because of the periodical production of a large number of eggs by the female and many sperms by the male; both eggs and sperms are living and as such have been grown. The production of the living germinal substance, especially the egg, utilizes a large amount of energy that is indirectly supplied by the food eaten. (3) The body of the frog, while in a large measure subject to the surrounding temperature, does utilize energy to some extent in the production of heat. This keeping the body warm is a more conspicuous expenditure of energy in birds and mammals, where a constant bodily temperature is maintained. Unless the frog can meet these three needs of the body it soon dies.

Kinds of Foods.—The easiest classification of foods is the one that divides them into non-nitrogenous and nitrogenous. In this first class are found the carbohydrates and hydrocarbons or fats; while the second includes the proteins. The fundamental distinction between these three kinds of foods depends on the structure and composition of the molecule of each.

But three atoms, carbon, hydrogen, and oxygen are present in the non-nitrogenous foods. All carbohydrates have the hydrogen and oxygen combined in the same proportions as water, H_2O, as is shown in the starch molecule, $C_6H_{10}O_5$. The structure of this molecule permits a number of variations which one might visualize by taking 6 blocks of one size and shape, 10 blocks of another size and shape and 5 more differing from the first two sets. With these

21 blocks various piles might be made. The main chemical difference between carbohydrate and hydrocarbons is that the restrictions placed on the relation between hydrogen and oxygen in a carbohydrate do not hold for fats. This would permit one to arrange his 21 blocks differently.

Carbohydrates are a class of foods that are manufactured in plant cells under the supervision of special bodies found in green leaves. These bodies are the chloroplasts which are bright green in color due to the presence of a pigment commonly known as chlorophyle. (Fig. 85.) In such bodies water and carbon dioxide (H_2O plus $6CO_2$ equals $C_6H_{12}O_6$ plus $6O_2$) are combined into starch, a body that now has food energy for both animals and plants. As we thus trace the source of carbohydrates, we discover a fundamental distinction between animals and green plants. The green plant can manufacture food-energy out of chemical bodies that yield no such energy when used alone. It takes energy to unite water and carbon dioxide into starch and this comes in large part from the sun. Until man discovers how to control artificially this chemical change he is dependent entirely on plants for his carbohydrate foods.

The carbohydrates are classified as monosaccharids where are found the most important simple sugars, such as dextrose ($C_6H_{12}O_6$); as disaccharids, such as maltose from cane sugar and lactose from milk sugar ($C_{12}H_{22}O_{11}$); and polysaccharids, of which starch, dextrine and cellulose are best known ($C_6H_{10}O_5$).

Fats are widely distributed. They are stored in the seeds, roots or fruit of plants, and all animal tissues contain a varying amount, being especially abundant in bone, marrow and adipose tissue.

Some of the common animals fats are stearin in beef suet and butyrin in butter. Most fat is a mixture of several individual fats. "Thus the ordinary mutton fat contains more tristearin and less triolein than pork fat." Human fat contains from 67 per cent to 85 per cent of triolein.

The non-nitrogenous foods are easily diffusible and serve as the natural fuel supply of food-energy for the body. It is believed that they do not serve to repair exhausted tissues but it is important to keep in mind that it is the living matter that is oxidized and not these foods. As the non-nitrogenous foods take their place in living matter and in turn assist in producing more heat, they repair tissues. When these foods are in excess they are stored as glycogen in the liver or as fat in the various parts of the body. When the frog is placed in a cooler temperature than usual, there is an increase in the amount of

sugar in the blood, thus revealing a close correlation between the use and need of more heat energy.

Proteins.—One of the chief constituents of living things is protein. This is a complex substance always containing carbon, hydrogen, nitrogen, oxygen; while sulphur, phosphorus, iron, copper, iodine, manganese and zinc are of frequent occurrence in the protein molecule.

The frog secures his proteins from the flesh that he eats, as all lean meat belongs to this class of foods. As the frog is not very particular in the selection of his food, he may get some plant proteins. Recently the biological chemists agreed upon the following classification for plant and animal proteins: Simple proteins, conjugate proteins and derived proteins.

The simple proteins are such substances as albumen in egg and some vegetables, or the globulins, fibrinogen or plant vitellin. The simplest proteins are the protamines found in fish sperms. The conjugate proteins have the protein molecule united with some molecule or molecules other than a salt.

The conjugate proteins include the nucleoproteins in which nucleic acid is united with the protein, glycoproteins which contain a carbohydrate, phosphoproteins, hemoglobins where hematin is the combining form, and lecithoproteins. This group of the proteins is subdivided into many distinct substances, the discussion of which belongs to organic chemistry.

The third class of proteins is the derived proteins, which should not be confused with the natural proteins existing as simple and conjugate proteins. These are all derived through digestion. As the protein molecule is thus transformed and becomes soluble certain stages are recognized, and each of these gives definite chemical reactions that enable the expert to recognize six classes.

Proteins are so complex chemically that their formula is not accurately known; one writer in order to show the complexity of egg albumen has proposed the following empirical formula: $C_{204}H_{322}N_{52}O_{66}S_2$.

Proteins are non-diffusible, are coagulated by heat and are usually called nitrogenous foods. Explaining their use to the frog in terms of what is known about higher animals, it can be said that proteins perform the definite work of renewing the wornout and exhausted parts of the organs. In fact no other kind of food can do just this work nor does any other class of food stand in such close relation to the vital processes of the frog. Oxygen, nitrogen and all of the other elements exist in the air, but they cannot be used in the repair of the organs because they are not combined into protein molecules.

Mineral Matter.—When any organism is subjected to a chemical analysis there are found small quantities of calcium, phosphorus, potassium, sulphur, sodium, chlorine, iron and iodine. These elements are combined in the living body and perform an important work. Ordinary table salt furnishes the element chlorine necessary in the manufacture in the body of hydrochloric acid. The bones of the skeleton are largely composed of calcium phosphate. In the brain are found a number of complicated bodies known as phosphatids. Iron is needed to form the red pigment in the blood. These mineral bodies do not undergo any change before being absorbed into the blood. Some investigations now in progress in the several great institutions for research in nutrition suggest that the minerals have a much greater influence on health than was believed. It is only necessary to indicate that calcium is absorbed more rapidly and extensively under one set of conditions than another, the significance of which is not yet understood.

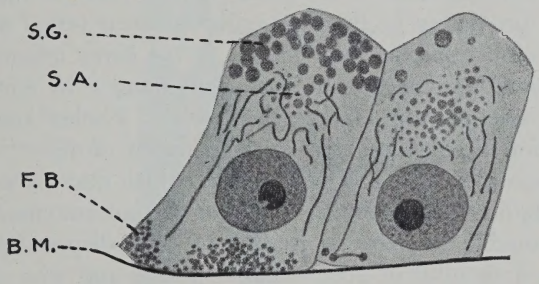

FIG. 18.—Two cells from the pancreas of the frog; the one on the right shows numerous secretion granules, *S.G.*, which are believed to contain the enzymes of the pancreas. Additional granules are in the process of formation in the area indicated by *S.A.*, the secretion area. The cell on the left has discharged its secretion granules. *F.B.*, fat bodies of uncertain function. *B.M.*, basement membrane. There are other structures believed to be associated with secretion and the whole problem is far from settled. (From Saguchi.)

Digestion.—The first man to suggest that digestion was a form of fermentation was Van Helmont (1577–1644), but he associated the idea of fermentation with a vital spirit which was in keeping with the dogma of his time. Remur (1683–1757) was the first person to show the influence of the stomach juice on digestion. His observations were scientific because they could be easily repeated. He caused his falcons to swallow metallic tubes filled with foods. These tubes contained numerous holes. After the tubes had remained in the stomach for a given length of time they were removed and it was

observed that the food had undergone definite changes. Spallanzani was the first to remove gastric juice from the stomach. He forced his tame eagle to swallow a sponge fastened to a cord. When the sponge was removed and the juice squeezed out he applied this juice to food and found that the same change would take place outside of the stomach. Most of the foods have to undergo important changes before they pass through the walls of the digestive tube. These changes are induced by what are called digestive secretions. A secretion is defined in biology as follows: *Any substance which is the product of living cells and serves some useful purpose in the economy of organisms may be called a secretion.* In this sense every secretion has been a part of the living substance of some part of an organism and is usually produced in what are known as glands, such as the liver or pancreas, in other instances the gland is a small part of the inner wall of the stomach.

The digestive secretions are known as enzymes, a term coined by Kuhne, in 1878, because of the nature of the changes that they are capable of producing in the food. In chemical terms we describe *an enzyme as a catalytic agent formed in the living organism.* Such bodies initiate and accelerate chemical changes in another body without undergoing any change themselves. Fischer speaks of the specific action of enzymes, that is, the capacity of digestive enzymes to attack one substance and not another which may even be closely related. Halliburton illustrates the work of an enzyme by saying: "we may roughly compare an enzyme to an ill-disposed person who comes into a roomful of good-natured people and who succeeds in setting them all by the ears. He has produced a change in them by his mere presence without undergoing any change himself. He is, moreover, able to repeat the process over and over again in fresh roomfuls *ad infinitum.*"

The stomach of the frog contains many glands that produce gastric juice which consists of a small amount of hydrochloric acid and the enzyme, pepsin (Fig. 19). Pepsin acts on the proteins only and transforms them into a substance that will pass through the inner layer of the digestive tube. It is difficult to understand how this change is brought about and especially the extent of the changes which take place in the protein molecule up to the time that it takes the form of an amino-acid, for the pepsin is the same as when it was set free from the glands and poured into the stomach, but the molecule of protein has undergone a great change, the details of which are known as fermentation, and since pepsin acts just as readily in a test-tube as in the

stomach, *i. e.*, apart from the living gland that produced it, it is called an unorganized or non-living ferment. All of the digestive ferments are unorganized.

When the gastric enzyme has done its work the residue of undigested proteins, the fats and the carbohydrates pass into the intestine to come in contact with the alkaline secretions of the pancreas and liver where the process of digestion is completed. The pancreas of the frog has the faculty of secreting three distinct enzymes, each specific in its action. These are trypsin, which converts proteins into amino-acids, amylopsin, which changes starches into sugars, and steapsin,

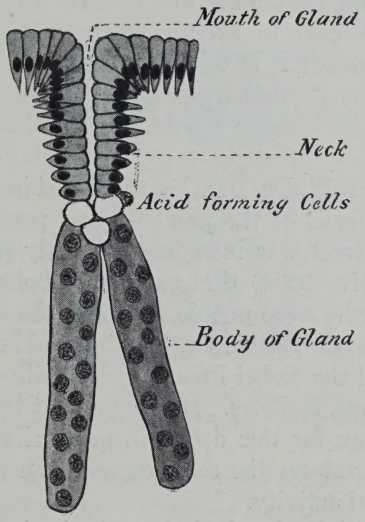

FIG. 19.—Gastric gland of frog.

which causes a splitting of fats into fatty acids and glycerin. The bile assists in emulsifying the fats, *i. e.*, the fat becomes transformed into minute globules, which give a milky appearance to the liquid. The several digestive enzymes act as accelerating agents merely, for all of these changes would eventually take place if given sufficient time. The speed with which these changes take place is much greater under the influence of the living cells than when they occur in a test-tube, for example. Mathews says: "Living matter is hence peculiar in the speed with which these hydrolytic, oxidative, reduction or condensation reactions occur in it; and it owes this property

to various substances, catalytic agents or enzymes, found in it everywhere." (*Physiol. Chem.*, p. 10.)

Secretin.—As the food passes from the stomach into the intestine why should the pancreas and liver pour their secretions through a duct and into the intestine when there can be no contact between the food and these glands as there is in the stomach? For a number of years it was assumed that these glands were all under the control of the nervous system. This is a fact so far as the stomach glands are concerned, but not for the liver and pancreas. What is the difference in the regulation of these two sets of digestive glands? When the acid food of the stomach reaches the intestine, it reacts on a substance secreted by the lining membrane, and changes it into a chemical body termed *secretin* (Greek, to excite). Secretin is absorbed at once, passing into the blood; it is then carried to the pancreas where it excites the pancreas to discharge its enzymes so that they can act on the several foods. Secretin acts also on the liver in a similar manner.

During the year 1922, Dr. Banting succeeded in isolating the secretion of the insula cells of the pancreas and proved experimentally that when this extract was introduced directly into the body (not through the digestive tract) that sugar metabolism was restored in those individuals who were unable to utilize the sugar of their diet. For this brilliant investigation, Dr. Banting and his teacher McLeod, have been awarded the Nobel Prize. The inability to utilize sugar is known as the disease, diabetes. It is important to keep in mind that insulin is not a cure for this defect in metabolism and there is no indication that it restores the cells, the non-functioning cells of the pancreas, to normal activity.

The digested food is absorbed through the internal layer of the digestive tube (Figs. 20 and 42) and passes into the blood, where its course will be followed in the next chapter. The use of the word absorb does not convey an accurate idea of just what is meant by the process. In this passing of food through an animal membrane, the lining epithelium of the digestive walls, there is the physical process of osmosis to which must be added probably some action on the part of the living protoplasm of these cells. Just what this action is cannot be fully stated.

The fate of the digestive secretions illustrates one of the strange wastes of Nature. After the several foods have been rendered soluble and diffusible, in other words, digested, we are led to believe that there is just as much of the several enzymes as when the digestive

process began. The body of the frog absorbs but a small portion of them and the remainder pass from the body with the indigestible parts of the food. If Nature provided some way of collecting and using these secretions again, there would be a large economy in the life of every animal. The need for food and the principles of digestion are common to all forms of life.

The food-energy which has been taken into the digestive canal has not become a part of the living animal as yet. It has cost the frog energy to manufacture digestive enzymes and their work has been to transform the foods into solutions of such a chemical nature that they will pass through the lining membrane of the intestine into the blood.

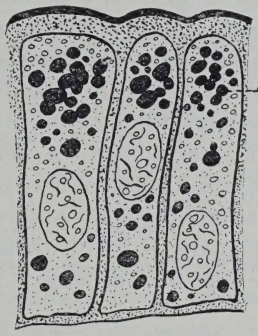

FIG. 20.—Epithelium of frog, showing fat globules passing through the living epithelial cells of the intestine. (After Krehl.)

Vitamins. The term vitamin was coined by the Pole, Casimir Funk, and is used to describe a very common ingredient of nearly all of the common foods of man. The chemical nature of these mysterious substances is unknown. Nor do we know the mode of action of vitamins, although there are four or more, yet we realize their great practical value in the prevention of scurvy and other grave diseases, and their importance in the promotion of health. Because of the uncertainty concerning the chemical nature of these mysterious bodies, they are distinguished as vitamins A, B, and C. These accessory food factors are present in butter, cream, milk, liver, kidney, beef, wheat, beans, carrots, cabbage, lettuce, nuts, etc. Not all of these foods contain all three but many of them do, so that a normal person living on an ordinary diet containing a reasonable amount of fresh vegetables is certain of obtaining a plentiful supply of vitamins which, when taken in excess, can be stored up for future use.

These vitamins are necessary because the diseases known as scurvy, beriberi, and possibly pellagra, are due to their absence in foods. Each of the vitamins seems to be associated with a definite one of the disorders. "Records compiled during the War of Independence for a period of six and a half years show that there had been some 30,000 cases of scurvy, about 400 of which ended fatally. The cases were very frequent where the ordinary rations were supplemented by dried vegetables. At posts which could readily be supplied with potatoes only the taint was manifested."

The presence of soluble C vitamin in the food is all that is necessary to prevent the disease known as scurvy. The vast importance of this discovery is appreciated from the quotation cited. In the past scurvy was also a very common trouble on long fishing voyages, but now this suffering and death is entirely preventable by simply furnishing the proper foods. In a similar way, water soluble B vitamin cures the disease known as beriberi. There is a difference of opinion in regard to the cause of pellagra for a recent investigation reveals the important fact that amino-acid plays a very important part in regard to this disease. Further research may reveal the fact that the vitamins themselves are a form of amino-acid. If this is true, then the cause of pellagra will be associated with those other diseases which are clearly proved to be due to a deficiency in one or more of the vitamins.

The fundamental generalization established in this discussion of the physiology of digestion is that the several forms of activity in organisms are in the last analysis, a transformation of energy. So far as it is known these changes within an organism conform to similar changes in inorganic nature. The several classes of foods and oxygen are the main sources of organic energy. Foods undergo digestion through the action of enzymes which are manufactured in the several digestive glands of vertebrates. Similar enzymes are present in all organisms although separate glands may not be present. Animals are dependent on green plants for the production of foods. The synthetic property of chloroplasts affords a basis of distinction between plants and animals. Digested foods pass by osmosis into the blood and are carried to all parts of the body of an animal possessing bloodvessels. In others the passage is in irregular lymph spaces or through the living material. The difference in concentration causes foods and oxygen to move into the body and waste to pass out. In the following chapter the analysis of other organs is considered.

For References, see Chapter IV.

CHAPTER IV.

CIRCULATION—METABOLISM.

Heart.—The blood of the frog follows well-defined routes as it travels to all parts of the body, and in this particular the frog belongs to the higher rather than to the lower class of animals. These routes of travel for the blood are the arteries, which carry it from the heart, and the veins, which return it to the heart. The heart is a most interesting organ because of its origin and work. Could you observe the heart as it first begins to beat and force blood along in the embryonic bloodvessels, you would not recognize in it the adult, conical, compact heart but rather an elongated branched structure which passes through a series of complicated changes before the adult structure is reached. This wonderful propelling organ for the blood is a gradual growth, and it took Nature a long time to evolve it. The work of the heart is to force the blood continually through the bloodvessels. It contracts slowly as compared with the human heart, but evenly and uniformly during the active season; while during hibernation the beats are feeble and slow. The fact that a structure exists which works regularly day and night, week after week, year after year, and only rests seconds or fractions of a second at a time, is a constant source of wonder.

Some appreciation of this intrinsic property of the cells of the heart to contract is gained from experimental studies upon the embryonic heart. When some of these cells are isolated in a culture medium suitable for their growth they grow and eventually unite in various patterns. After union the cells begin to beat in rhythm, although entirely detached from the embryo (Fig. 32).

The frog's heart is situated just anterior and ventral to the liver. It is surrounded by a thin membrane, the pericardium. The heart is made up of three parts: (1) The conical ventricle, with the point directed posteriorly; (2) the two auricles, right and left, which are in front of the ventricle. A thin membrane divides the two auricles into separate chambers. The right auricle receives venous blood from the body and the left auricle oxygenated blood from the lungs. Both auricles empty their blood into the single ventricle, which

in turn contracts and fills the arteries. As the blood leaves the ventricles it enters the large bulbus arteriosus, which forms two branches that give rise to the aortic arches (Fig. 1). The details of the heart, arteries and veins should be worked out in the laboratory.

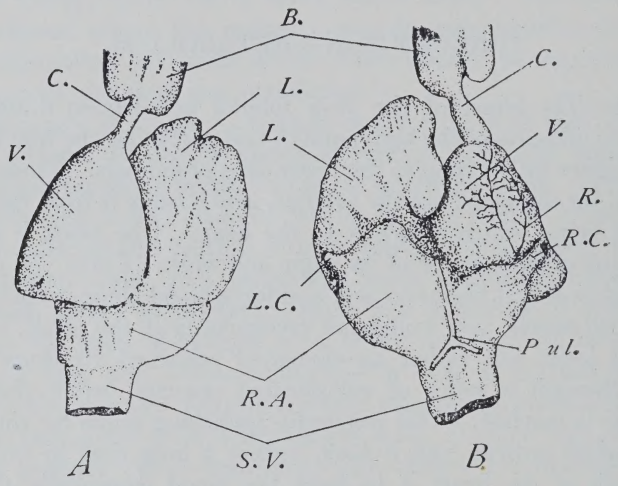

FIG. 21.—The heart of *Cryptobranchus*. *A.*, ventral aspect; *B.*, dorsal aspect. *B.*, bulbus arteriosus; *C.*, conus arteriosus; *L.*, left auricle; *L.C.*, left anterior vena cava; *Pul.*, pulmonary vessels; *R.*, coronary vessels; *R.C.*, right anterior vena cava; *S.V.*, sinus venosus; *V.*, ventricle. (Reese.)

Blood.—The blood of the frog consists of corpuscles and plasma. There are three kinds of corpuscles: (1) The red, which are oval in outline and contain hemoglobin. The work of the hemoglobin is to carry the oxygen from the organs of respiration to all parts of the body. (2) The white corpuscles, smaller than the red and irregular in shape. They are factors in the clotting of blood (Fig. 22), the destruction of foreign bodies, such as disease germs, and the removal of degenerating parts. The white blood cells, or phagocytes, change their form much as an ameba does, and consequently have the power of independent locomotion, so that they pass through the thin walls of the capillaries and out into the spaces between cells, and are found in all parts of the frog. As they thus migrate around in the body minute foreign particles, such as bacteria, are met with and eaten (phagocytosis). Their method of eating will be better understood after the study of the protozoa, where a similar method of eating is the usual process. These white cells also help to remove

broken bits of tissue, as in the removal of the degenerating tail. (3) The spindle-shaped corpuscles are colorless except during the spring when they acquire hemoglobin and are transformed into red blood corpuscles. They are smaller than the true red corpuscles and may change their shape somewhat. Besides forming new red cells they assist in the clotting of the blood. The blood corpuscles wear out like the other parts of the body and have to be renewed. The marrow of the bones is one of the most important sources for the origin of new blood corpuscles. The plasma of the blood is straw-colored or else colorless in appearance. It contains the various

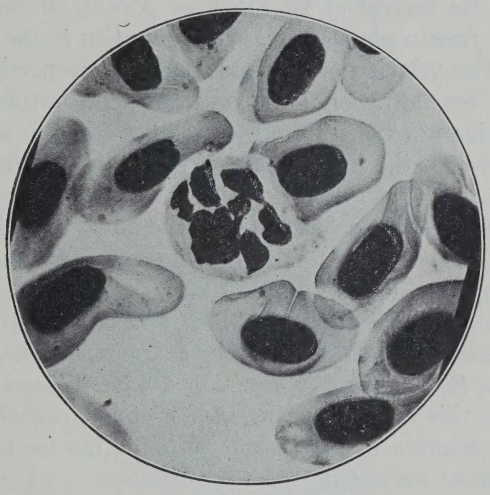

FIG. 22.—Photomicrograph of blood of necturus. Compare the oval nuclei in the red corpuscles with the polymorphic nucleus of the white corpuscle in center of figure.

transformed foods, water and salts, as well as the waste products of the body; hence its chemical composition varies from day to day and from season to season, being influenced largely by the animal's amount of activity and its food supply.

The lymphatic system does not occupy definite lymph vessels but consists of several large, irregular-shaped lymph spaces. Some of these can be easily dissected and their boundaries determined as the skin is removed. These subcutaneous spaces are separated by thin septa of connective tissue. The colorless lymph flows into the blood through the four lymph hearts. A pair dorsal to the anal opening can easily be seen beating in the living or recently killed frog.

Definitions.—The various substances which are used by a living organism exist in Nature as gases, liquids, or solids, but are always dissolved in a solution when they are taken into the living substance. A number of definitions are used in describing the manner in which these several forms of matter enter and leave the living organism. The following definitions are in agreement with the usage of the writers who base their explanations on physiological chemistry.[1]

When gases are mixed there is a rapid dispersion of the molecules of each until both become equally distributed. When two fluids of different densities are mixed, the particles of each will be dispersed in the same manner as in the mixing of gases. This is called diffusion. *Diffusion is the process of migration of gaseous or liquid particles which wander from a place of higher concentration to one of lower concentration.* The velocity of this movement is proportionate to the difference in concentration at a constant temperature. Thus we have the passing of oxygen from the air where there is a greater concentration through the lungs or the skin of the frog into the blood where the oxygen is of a lesser concentration; and likewise we have the passage of the carbon dioxide from the blood into the air for the same reason. The digested foods in the intestine are in a solution and separated from the blood by a membrane. It is common knowledge that these foods do pass into the blood and *this process of diffusion when taking place through a membrane is called osmosis. Osmosis is defined then as the passage of a solvent or a solute through a membrane.* The solute in this case is the digested proteins, carbohydrates and fats, and the solution is the water containing the foods. The word osmosis is a more restricted term than diffusion.

But why should the oxygen or the digested foods pass into the blood-stream, or the urinary waste pass out of the blood-stream? A simple experiment will help in explaining this important problem. When two fluids of unequal density are separated by an animal membrane (Fig. 23), the liquid flows toward the denser solution forcing this to rise above the surrounding fluid. Such pressure is known as osmotic pressure. If the contents within the egg membrane shown in this figure were free to pass into the surrounding medium then the osmotic pressure would be reduced in proportion to the equalization. But the direction which the liquid takes will depend upon the concentration within the living organism. In the one case, the movement is into the living cells as in food; in the other case it is away from the

[1] Bayliss: Physiology, p. 157. Hill: Recent Advances in Physiology and Biochemistry, p. 622. Mathews: Physiological Chemistry, p. 199.

living cells, as in the urinary wastes. In a similar manner we may, in imagination, let the egg with its surrounding membrane stand for any cell in the body of an animal organism. These cells are surrounded by more or less of the liquid lymph. In this lymph are the foods and the oxygen in solution. As the cell carries on its activities energy is utilized that must be replaced. Such activity results in a lower concentration for these substances and they readily pass by

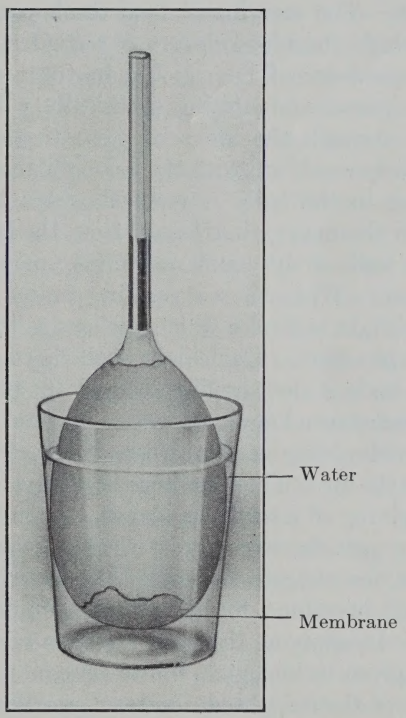

FIG. 23.—Diagram of simple osmometer. The water in the glass passes through the egg-membrane and forces the egg-white up in the glass tube.

osmosis into the living cell. The rate of this passage will depend in part on the difference in concentration between each cell and the surrounding lymph. It is in some such way as this that non-living materials are brought into the living cells. Just how these particles are made living is unknown.

There is also a growing opinion that the living cells participate in the passage of any solvent or dissolved particle from one position to

another in the bodies of plants and animals, which constitutes an additional factor of great importance. This makes it necessary to say that such substances pass by osmosis and the action of living cells. It is certain that living cells regulate and control this passage, for it is well known that oxidation does not increase when a man is placed in a saturated atmosphere of oxygen. The part played by living cells in regulating the in-take and out-go of matter is not well understood.

Respiration.—The carrying of food to all parts of the body is but one work which the blood does. A second is its relation to respiration; the presence of hemoglobin in the red blood corpuscles is for the sole purpose of uniting chemically with the oxygen as the blood flows through the lungs or close to the skin. The oxygen becomes loosely combined with the hemoglobin, with which it remains until a place in the body is reached where there is a scarcity of oxygen, then the oxygen is released from the hemoglobin and passes through the walls of the capillaries to take part in the vital activities of that region. When the oxygen first unites with the hemoglobin it gives it a bright red color which darkens as the oxygen participates in the vital processes. Coincident with this taking of oxygen to all parts of the body is the carrying away by the plasma and hemoglobin of a waste substance known as carbon dioxide. The carbon dioxide is carried to the lungs or skin, where it leaves the body of the frog, passing into the air. Thus the frog is continually taking oxygen from the air and giving off a waste substance, carbon dioxide, to the air. If certain other agencies were not at work we could easily believe that after a time the oxygen content of the air would become so much reduced that breathing for all animals would become difficult or impossible. In applying the term waste to carbon dioxide a definite meaning is given in biology. *Waste substances are such as have once been a part of the living body and are produced as a result of some expenditure by the living organism. In this sense waste and excretion have the same meaning.*

The frog, like all living things (except certain bacteria), uses this oxygen in a definite manner, which is characterized as one of the fundamental vital processes. Lavoisier, in 1792, pointed out that the use of oxygen in respiration was a chemical process. That heat was produced by living things and ceased with their death was known from the earliest times. But not until the discovery of oxygen in 1771 was it possible to understand how this heat was formed in living things. This suggestion of Lavoisier is really the beginning

of the modern physiological study of biology, because his suggestion showed that chemical elements and compounds behave in a definite manner in living things, thus furnishing a scientific starting-point for such explanations. The value of the scientific point of view in this connection is well illustrated by the following: Oxygen exists in the atmosphere as O_2 molecular oxygen and in very small quantities as O_3 ozone. When these two chemical bodies are brought in contact with living protoplasm more heat is furnished by O_3 than O_2. If this difference is computed there are found to be 32,000 more energy units (calories). At first thought this seems to be a very great difference, but if an equal amount of coal is first burned with O_2 and the same amount could be burned with O_3 there would result approximately 20 per cent. more heat. The percentage of differences is probably much higher in living protoplasm but not as great as one would infer from the figures, 32,000. The important fact to be retained from this illustration is that heat is constantly being given off as molecules undergo simplification in the several aspects of metabolism. On the other hand we must assume that heat is taken up by these same chemical changes in metabolism, as, for example, when food-products are gradually built into complex bodies similar to protoplasm which occurs just before food becomes protoplasm.

In any discussion of respiration it must be remembered that respiration is a vital process that takes place within the living protoplasm, and as the oxygen reacts on carbon, energy in the form of heat is supplied. This is known as oxidation.

Excretion. The more important wastes of animal organisms are carbon dioxide, water, certain sulphates, phosphates, chlorides and nitrogen wastes. During the destructive phases of metabolism there comes a time when the chemical changes cease to yield energy to the living body. Carbon dioxide is chiefly given off by the lungs in man where the removal by diffusion of this waste from the blood to the air takes place. Some carbon dioxide may be removed by the kidneys, while the skin of the frog is by far the most important organ that participates in freeing the body of this waste. Water is also an end product of metabolism and must be removed. The kidneys, skin and lungs participate in this exchange.

The kidney is composed of numerous tubules lined with cells (Fig. 24). A single tubule consists of a filtering apparatus (the Malpighian body) and a glandular portion. In the Malpighian bodies wastes are strained out of the blood, while in the glandular portion of the tubules wastes are excreted. It is believed that these cells

elaborate from the wastes in the blood such excretory products as the chlorides, sulphates, phosphates and others and this is to be interpreted as similar to the glandular activity of the pancreas or liver.

The urea contains the larger part of the protein wastes of metabolism. Urea is formed through the action of the liver on similar nitrogenous bodies. After being formed in the liver it passes into the blood stream, and is carried to the kidneys where it is filtered from the blood. Friedrick Wöhler in 1828 succeeded in artificially manufacturing urea. This was a great discovery because it demon-

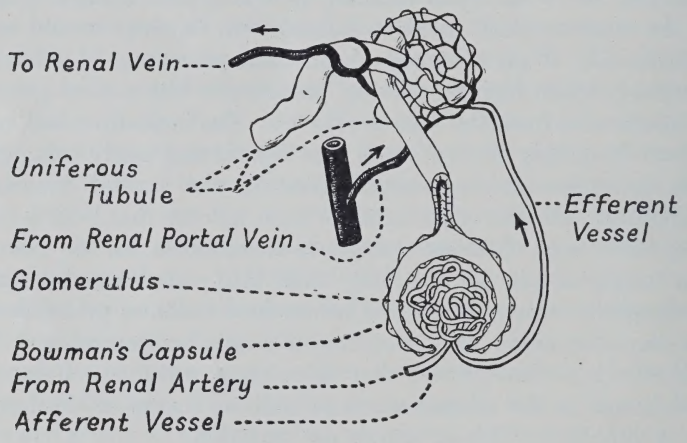

FIG. 24.—Diagram to show the relation of the renal tubule to the bloodvessels and to the Malphigian body. The Malphigian body consists of Bowman's capsule, and the glomerulus in which the afferent bloodvessel breaks up into capillaries. These in turn unite to form the efferent vessel. (Redrawn from Guyer.)

strated that some of the products of metabolism could be produced by following a definite chemical procedure. Since this time a large number of organic products have been artificially produced. The study of the wastes found in the blood is one of the modern problems that is yielding a deeper insight into the activities of life processes.

Metabolism.—The nature of the several excretions and the character of the food in the blood tell much concerning the vital processes. More can be learned in an advanced course in physiology, but even then not a great deal is understood. There seem to be a number of constructive or up-building agencies, in the form of internal enzymes, which serve to make the combinations of the nitrogenous and non-nitrogenous molecules more like those that exist

in living substance, but there is still a wide difference between the two, and science has not yet discovered just how the food becomes living. How long the transformed food remains a part of the living substance is a matter of conjecture. The changes which initiate the breaking down of the living substance and the formation of waste products are also unknown, yet the two processes are taking place all the time in the body of the frog, the one in the nature of construction or up-building and the other destruction or tearing down. To cover these two widely different processes in the body the general term metabolism is used. "*Metabolism designates that complex of chemical changes in living organisms which constitute their life, the changes by which their food is assimilated and becomes a part of them, the changes which it undergoes while it shares their life, and finally those by which it is returned to the condition of inanimate matter.* Gathered together under this one phrase are some of the most intricate and inaccessible of natural phenomena." (Chittenden.) The single word metabolism is used to indicate one of the distinguishing characters of all organisms. In using the term in this way it is understood to include the changes indicated in the definition; and while these are many and divergent, yet they are a part of one vital process. Thus used metabolism serves to mark off sharply the activities of living substance from all forms of activity in non-living matter and is a distinguishing feature of living matter only.

Regulation of Metabolism.—The regulation of metabolism has long been a puzzle even to experts as they noted their failure to regulate gain or loss in weight, despite a liberal or even over generous intake of food-energy. The carbohydrates are rendered simpler during digestion; and, after they pass into the blood, are transferred to the liver where they are converted into glycogen. Whenever the organism needs carbohydrates for its different energy purposes, this glycogen is decomposed into glucose, and released into the blood stream where it is available for the needs of the body.

The influence of the glands of internal secretion in carbohydrate metabolism shows that excision or the improper functioning of the pancreas results in diabetes. A diabetic person cannot burn the carbohydrates of his food so as to get bodily energy out of them. The useless sugar passes off in the urine or accumulates in the blood, and the patient wastes away in spite of a large appetite. The secretion of the suprarenal stimulates the liver to release more sugar into the blood, and removal of the thyroid enables the body to assimilate

more than the normal amount of sugar. The discoveries thus far reveal that heat production is subject to several checks and balances. It is not to be assumed that these endocrine glands control the rate of metabolism entirely although they play an important role. These experiments suggest that the over-activity or under-activity of some of these glands may be responsible for marked underweight or overweight. There are additional factors such as exercise, diet and the generally inherited tendencies of slenderness, or stoutness. Some further light is thrown on this problem from the study of gigantism and dwarfism. The excessive growth in the skeleton which results in abnormally large individuals is due to excessive activity of one of these glands. When the thyroid is absent or does not function stunted growth follows. This latter defect is often corrected by feeding the thymus or thyroid glands. These abnormalities help us to appreciate that there is an important part taken by these glands in regulating the normal activities of an animal. We may expect important discoveries in this field which will tell us more about the regulation of metabolism.

Hibernation and *starvation*[1] are two closely allied phenomena. In both instances the organism sustains itself by utilizing energy stored within the body. Until the discovery of internal enzymes little was known concerning the physiology of these conditions. It has been known for some time that the muscles of the frog become lighter during hibernation, but what the agent was that enabled the frog to withdraw energy from muscles was not understood. The writer has experimented with some fish and has been able to keep one without food for twenty months. The result was that the muscles became very much reduced and the fish was hardly able to move. A similar condition exists in human beings in the case of a fever or tuberculosis. The body becomes very much lighter and emaciated. What has become of all of the energy stored in the muscles in all these illustrations and how has it been utilized? The most widely accepted theory at present is that the internal enzymes may reverse their action when there is a demand for food-energy and attack the muscles. This is known as the reversibility of internal enzymes. In these cases of hibernation, starvation and emaciation from sickness it is probable that the internal enzymes are the agents that release the food energy that exists as muscle which thus freed is carried by the blood to such parts of the body

[1] Benedict: The Influence of Inanition on Metabolism, Publication 77, Carnegie Institution, Washington, 1907.

as demand food to keep the organism living. A chemical examination of the blood of a starved fish and of one recently caught revealed the fact that there was about the same amount of food products in each.

Metabolic Water.—That water is necessary to life has been known for a long time. During development it is the most abundant constituent, ranging from about 40 per cent to nearly 100 per cent. This demand for water enters into the very life of the cells and is satisfied from imbibed water and from metabolic changes in the food. The imbibed water serves to dissolve nutrients, to act as a medium for their distribution, to remove injurious waste products and to influence temperature to some extent by the amount of evaporation.[1]

The metabolic water is chiefly derived from the oxidation of nutrients. The carbohydrates, fats and proteins all contain hydrogen, and their complete oxidation as they are built up into living protoplasm or take part in the several vital processes produces a certain amount of water. "Thus 100 parts of cellulose or starch $(C_6H_{10}O_5)_n$, containing 6.17 per cent. of hydrogen, give 55.5 parts of water. Most fats yield more than their weight of water, while proteins when completely oxidized give from 60 to 65 per cent of water. (Babcock.) The several nutrients are oxidized in the cell protoplasm. Here the formation of water in the protoplasm gradually and continuously renders the nutrient solution within of less density than that without. Such a difference in concentration ensures a constant movement by osmosis toward the points where foods are needed.

The rate of oxidation is greater in animal cells than in plants, consequently there is a greater amount of waste in animals. This is especially the case with soluble products arising from protein metabolism. These are excreted through the kidneys in the urine in the form of urea in fishes, amphibia and mammals, while in birds, reptiles and insects most of the nitrogen waste is in the form of uric acid or its ammonia salt. These are practically insoluble in the body, so that the need for water in such animals is much less because the uric acid is not as poisonous nor its accumulation as dangerous.

In all animals the protoplasmic need for water is largely supplied by the metabolic water, and during hibernation the metabolic water is sufficient for all the vital needs. In such cases it is derived from

[1] Babcock, S.: Metabolic Water: Its Production and Role in Vital Phenomena.

the food energy stored in muscles and fat. In a similar way insects that live upon air-dried food and desert animals are able to supply their bodies with the requisite amount of water.

Phosphorescent Organisms.—In the analysis of organic activities emphasis is placed on the necessity of energy being available for this work. The transformation of the potential energy of foods into the many activities of living things is really an expression of kinetic energy. A further application of this principle furnishes still more convincing proof.

From the time that Aristotle wrote about the light given off from dead fish and damp wood until the present, observant students have wondered how this light was made. The number of animals that have this peculiarity includes fishes, insects, molluscs, worms, jelly-fish, and protozoans. In the plants certain mushrooms and bacteria are best known.

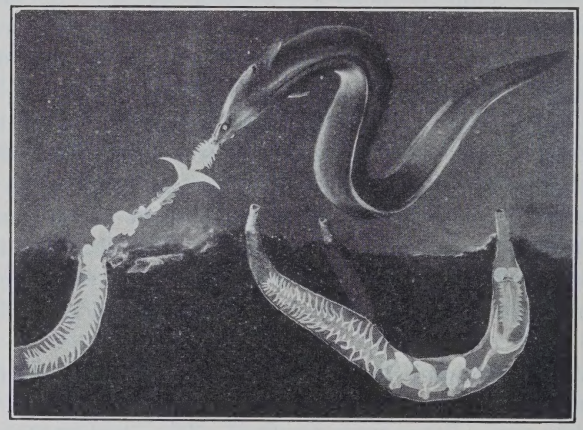

FIG. 25.—An eel hunting *Chætopterus* at night. The worm that is being seized is in full luminescence; another worm in a neighboring tube is beginning to light, stimulated by the commotion in the water occasioned by the attack of the eel. (Drawing by R. Bruce Horsfell, republished from the Journal of the Franklin Institute, from Dahlgren.)

Robert Boyle, in 1667, performed an experiment that gave the real clue to this secret although it was only recently that it was fully understood. Boyle placed some phosphorescent wood in an air-pump. As he removed the air the glow on the wood disappeared and as he re-admitted the air the glow returned. We know now that it was the oxygen of the air that was important.

The light of organisms is just like ordinary candle or electric light

except that it glows without giving off any perceptible amount of heat, while the heat given off by a burning candle is more than 9000 times as much. In the burning of the candle a great deal of energy is transformed into heat instead of light. This luminescence may take place within the substance of the organism or in the water or air. Wherever it glows the process is the same.

"First, it must be explained that all of this light is produced by the oxidation or burning of a substance named 'luciferin' that has been secreted in the living flesh or protoplasm of the organism's body cells. This substance, once so secreted, is no longer living material but is a product which may be used at once or may be stored, either in the living cell or in internal reservoirs, until it is needed to produce the light either in the living cells, in cavities of the body, or outside the animal in the surrounding water or air. Secondly, while the luciferin alone will oxidize without showing any light, it requires the presence of a second substance, also secreted by the animal's body and called 'luciferase,' in order that its chemical combination with oxygen shall produce the light. Strange to say, only very little, almost no heat is generated by this oxidation. In nearly every case the light amounts to more than 90 per cent of the energy released while only a fraction of 1 per cent of heat appears."

The *luciferin* is the body that burns and the *luciferase* is an enzyme which assists the oxidation although it does not take an actual part in the chemical reaction.

At last after many years of investigation living cells reveal another of their secrets and the explanation involves the same use of energy as movement or production of heat.

"The best known insects are the fire-flies and glowworms of our own and practically all other countries, and the fire-beetles, or cucujos, of the tropics. In all of these insects, which belong to two families of beetles, the Lampyridæ and the Elateridæ, it seems that the light cells are derived from modified fat bodies, one of the few cases where mesodermal elements have been used for this purpose. Their structure shows the common principle of a layer of light cells near and next to the integument, a transparent cuticle at that point, and a layer of reflector cells filled with crystals of calcium urate, which throw back the light so that all rays are directed outward. The oxygen is brought to the cells by the numerous tracheal capillaries that come to the organ and, according to the amount of control of this air supply, we find either a slow glow, as in the larvæ of the lampyrids (called glowworms) and in both larvæ and adults of the cucujos,

or we see a quick, sharp, well-timed flash or series of flashes, as in our common fire-flies, where the flashes are used by the insects as a distinguishing mark of their species in finding their mates among the mates of several other species all flashing at the same time. In these latter cases the end branches of the tracheal stems that carry the oxygen (air) into the light cells are provided with a radial muscle apparatus that not only controls the flow of air but actually can pump spurts of air into the light cells. The illustration shows some of these air-controlling muscle cells, which are called tracheal end cells." Dahlgren.[1]

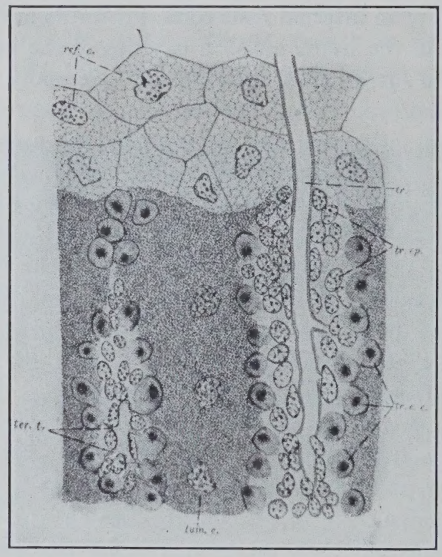

FIG. 26.—The cucujo belongs to the family of beetles known as Elateridæ. There is another family of beetles, the Lampyridæ, many of the members of which luminesce. Above is shown a vertical section through the light organ of a fire-fly, Photinus, one of the Lampyridæ. The lettering has the following significance: *tr.*, trachea; *tr. ep.*, tracheal epithelium; *tr. e. c.*, tracheal end cells; *ref. c.*, reflector cells; *lum. c.*, luminous cells; *ter. t.*, terminal twigs of the trachea. (From Dahlgren's and Kepner's Histology.)

The study of animal activities in this chapter has carried the analysis into the minute parts of the body. Food and oxygen have been followed from the digestive canal and lungs until each became a part of the living organism. The service which such substances

[1] Dahlgren: Phosphorescent Animals and Plants, Natural History, 1922, vol. **22**. Harvey: The Nature of Animal Light, 1920. Hess: Origin and Development of the Light Organs of Photurus Pennsylvanica, Jour. Morphol, vol. **36**.

yield to an organism is that they supply energy for heat, movement and growth. Respiration, excretion, starvation, hibernation and phosporescence, common forms of vital activity, were shown to be explained in terms of energy used or wastes (non-serviceable forms of energy) removed. It is assumed that foods and oxygen become a part of the living substance before yielding energy to the organism. These substances pass into the blood of the frog by osmosis and in a similar manner from the blood to the living cells. Not all of the substances in the food yield energy as this term is understood in connection with proteins, carbohydrates, hydrocarbons or oxygen. There are present in a well-balanced diet at least three unknown bodies, vitamins, A, B, and C. Experience and experiment clearly indicate that these mysterious substances are indispensable for health but there is no evidence that they yield energy.

Some of the agents that assist in regulating metabolism in living things are being revealed through a study of the influence of the endocrine glands. This is especially evident in the regulation of carbohydrate metabolism. These discoveries to date mark one of the most brilliant achievements of highly trained scientists and progress along this important phase of life must await their further experimentation.

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CHAPTER V.

CELLS AND TISSUES.

THE last great historical step in the development of biology completes the analysis of the structure of organisms and reveals that there is a single morphological and physiological unit, the cell. In the two preceding chapters we have intentionally used this term, cell, as the explanation of vital activities was carried to the most critical analysis possible at this time. What are the stages in this historical development and why is the discovery of the cell regarded as having placed the study of biology on a permanently scientific basis?

The term cell was coined by Robert Hooke, an Englishman, in 1665. He noticed that the vegetal tissue, cork, was composed of "little boxes or cells distinct from one another." What he actually saw was an outer limiting membrane around a cavity since the living part of cork is missing. Miscellaneous observations were made for the one hundred and seventy-five years following until the term cell had come to be quite universally recognized as a constant part of animals and plants but none of these earlier writers grasped their significance as the ultimate structural units in either plants or animals nor was the similarity of this structure in all organisms emphasized.

Cell Theory.—In 1831, Robert Brown discovered that there was present a constant structure within the cell which he called the nucleus. This observation paved the way for the final conclusion because it furnished a basis for comparing animal and plant cells. In 1831, the botanist, Schleiden and the zoölogist, Schwann, each announced that the structures termed cells were not only the same in all animals or in all plants, but that the cell was identical in all organisms. Schwann was the first to use the expression *cell theory* in his paper of 215 pages on "Microscopic Researches in the Structure and Growth of Animals and Plants," published in 1839. It has become customary to link these two names and give to each a share in having furnished a basis upon which all subsequent study of organisms is made. Many other investigators have verified their conclusions until no one ever questions the statements that: (1) The unit of structure in organisms is the cell; (2) the activities of the organisms can only be interpreted

in terms of the activities of the individual cells; and (3) every organism begins life as a single cell. "No other biological generalization," writes Professor E. B. Wilson, "save only the theory of organic evolution, has brought so many apparently diverse phenomena under a common point of view or has accomplished more for the unification of knowledge." This is high praise but great importance is attached to a law governing natural phenomena for we no longer regard this generalization as a theory. Only a few of the laws of life have been revealed to man. More will be discovered with the progress of

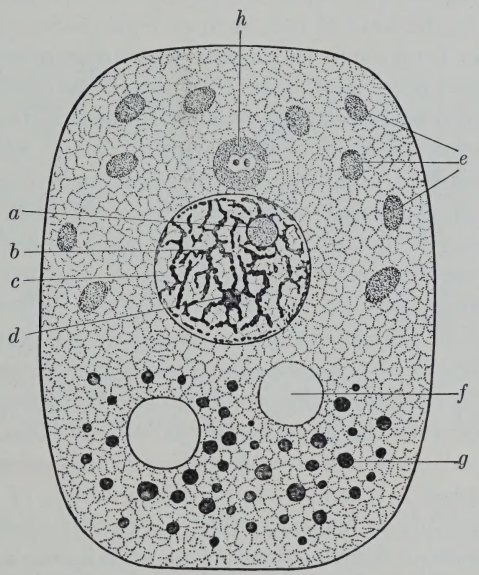


FIG. 27.—Diagram of a cell. *a-d*, nucleus; *a*, nucleolus; *b*, chromatin "network;" *c*, linin meshwork; *d*, karyosome, or chromatin knot; *e*, metaplasmic inclusions in cytoplasmic meshwork; *f*, vacuole; *g*, plastids in cytoplasm; *h*, centrosome, recently divided. (After Wilson.)

time. It is important that we understand how such laws are discovered. First of all, it should be emphasized that they are not something that man has created or produced. They have always been in existence since life began, and secondly, their final formulation is the result of many different minds studying the problem. Other men added to our information about the nature of the cell. Hugo von Mohl (1846) concluded that the living substance of the cell in all plants was the same and devised the term *protoplasm*. Dujardine (1835) had given the name *sarcode* to the living part of

animal cells. The notion gradually grew in the minds of biologists that sarcode and protoplasm were identical, but it was Max Schultze in 1861 who made this clear in his definition of a *cell as a mass of protoplasm surrounding a nucleus.* Kölliker in 1863 formulated the term *cytoplasm* which is used now to describe the living substance of the cell body other than the nucleus. In modern usage, then the protoplasm is the name given to the living material in cells which is differentiated into two parts: cytoplasm and nucleus.

Cytoplasm.—This portion of the cell presents a variety of appearances depending on whether it is observed in the living or lifeless state, as well as the kind of cell, such as bone, nerve, or muscle cell. One learns very little about the details of protoplasm until after suitable stains have been used. By this means the varied structural form of the cytoplasm can be made out. In some instances the cytoplasm is uniformly granular or fibrillar or alveolar. This latter term is used to describe the appearance presented when oil and water are mixed where a number of round vesicles are crowded together. Scattered among the cytoplasmic granules one may find various lifeless particles such as oil, water, food particles, or crystals that are either to become a part of the living protoplasm or are by-products of vital activity. The general term *metaplasm* is used for these lifeless bodies (Fig. 27). The specialized bodies, the plastids (Fig. 85), in the green plant cell are living portions of the cytoplasm and should not be confused with the metaplasmic inclusions. The granules and metaplasmic bodies are immersed in a clear ground substance. While we cannot express in chemical terms the relations of the chemical elements in protoplasm, we can safely say that it contains proteins. Due to the numerous forms of activity continually taking place in the cell the chemical composition is not constant. The cytoplasm is the generalized part of the cell and is usually surrounded by a limiting membrane of varying thickness and texture.

Nucleus.—The nucleus is usually of rounded form and embedded in the cytoplasm. There is a definite nuclear membrane in most instances when the nucleus is not dividing (Fig. 28). The structural plan of this highly specialized part of the cell is essentially like the cytoplasm. There is the nuclear lymph or *achromatic material* that corresponds to the ground substance of the cytoplasm; and the *linin meshwork* that is similar to the granular part. The most important part of the nucleus is a material that is deposited in the linin meshwork and frequently is so abundant as to obscure this framework. This substance is *chromatin.* When the cell divides, the chromatin under-

goes conspicuous changes that are described later (Fig. 28). There is usually a prominent round body in the nucleus, the nucleolus, that is regarded as a part of the achromatic substance.

Both cytoplasm and nucleus have their special work, we find as we analyze the functional activity of the cell. Life cannot continue in a cell when either part is lacking as the removal of the nucleus checks the regular metabolic events. This analysis into cytoplasm and nucleus represents the morphological limits in organisms. Life is unknown in any substance that cannot be resolved into a cell. All modern studies recognize this fact. When a new cell arises, it follows

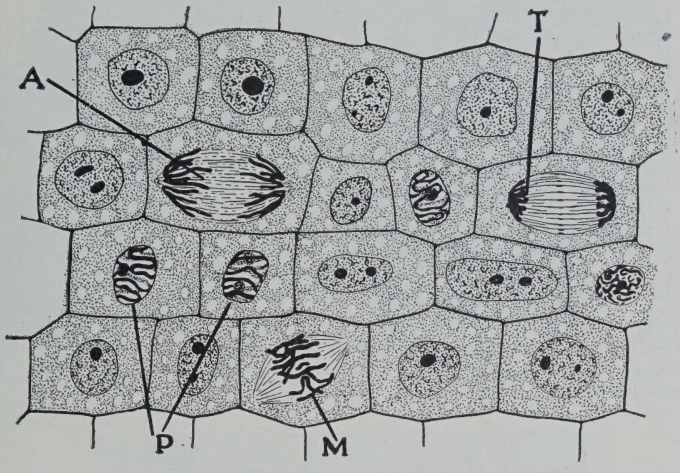


FIG. 28.—This drawing of the cells in a growing onion-tip shows a granular cytoplasm containing vacuoles; cells that have a round or oblong nucleus, with one or two nucleoli and chromatin granules; nuclei in various stages of division: *A*, anaphase, *M*, Metaphase, *P*, Prophase, *T*, Telophase. These cells also show a very simple tissue.

a regular series of changes that have become definitely fixed for each type of cell. Thus all modern studies that aim to understand the fundamental principles governing life are concentrated on changes that transpire in these microscopic bodies. (Figs. 29–32.)

Cells vary in size and shape enough to account for all the difference not only between different organisms but also to explain the many parts of an individual organism. Let us see how this is accomplished. In all microscopic studies of the parts of plants and animals there is revealed much variation in the size and shape of this unit of structure—the cell. In Fig. 31 it is readily seen how very different is the appearance of these two plants and all that we have to base the

distinction on is the size and shape of these cellular elements. The mere rate of growth resulting in thicker walls in the spring and summer gives us an entirely different picture.

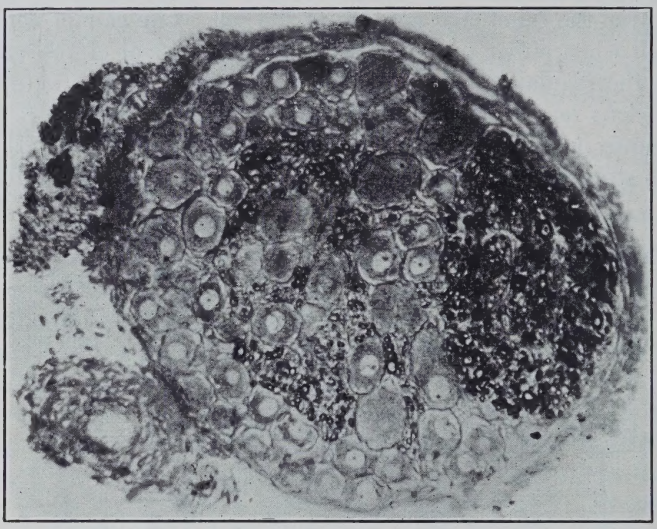


FIG. 29.—Photomicrograph of the cells in nerve ganglion of the box-turtle. These cells are similar in size and character although not united as in most tissues. The minute circles, surrounded by black, are cross sections of nerve fibers. From preparation made by Lucy Watt.

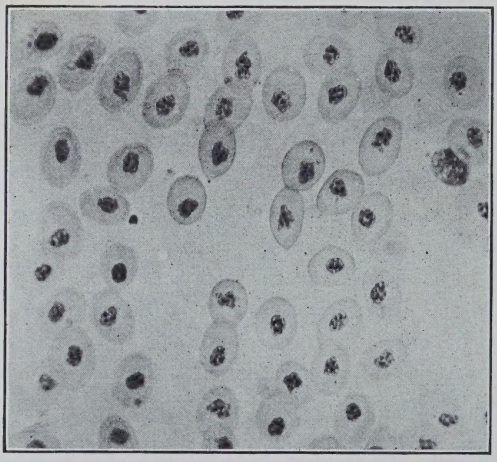
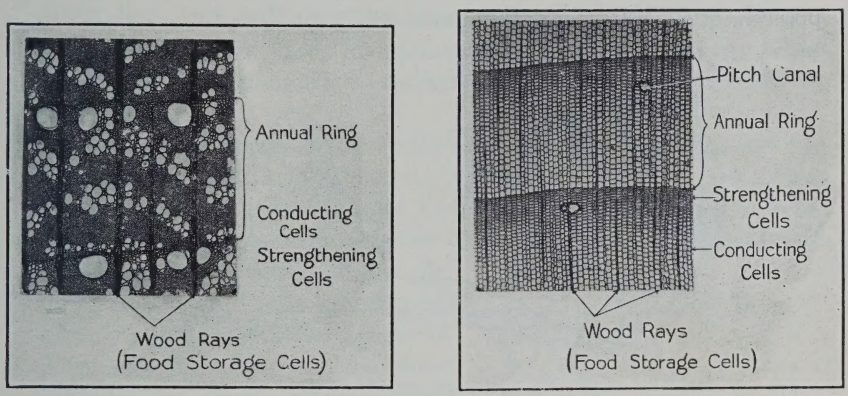


FIG. 30.—Photomicrograph of the blood of the fish Amia calva showing the red corpuscles only. These cells do not unite.

The Life of a Cell. It is common experience that after an animal has been killed, either accidentally or by the use of chloroform, that there is still movement in certain parts of the body. You have observed the beating of the heart of the frog after the frog itself had been killed. All cells live for a period after the death of the organism. Many of them develop granules which have a strong affinity for a stain known as neutral red. After the cells die, the color disappears from the granules and other changes take place in the cell. This enables one to test the rate at which various cells die after the death of the organism. The following facts were taken from experiments on the rat. When the cells were kept at 37° F., cartilage cells, kidney,



A *B*

FIG. 31.—*A*, Photomicrograph of very thin section of elm; *B*, the same from spruce. Notice that the differences in the wood rays, strengthening and conducting cells is due to variations in the shape of individual cells and the thickness of the cell wall. (Photographed by C. C. Forsaith, New York State College of Forestry.)

epithelium and muscles lived for two hundred and forty hours. Cells in the tongue and salivary gland, one hundred and ninety-two hours. Liver, pancreatic and brain cells, ninety-six hours. When the entire animal was left at room temperature the period of survival of the cells was very much shorter.

At the Rockefeller Institute for Medical Research, Dr. Carrell, in 1912, isolated a small portion of the heart of the embryo of a chick. These embryonic cells were placed in a suitable nutrient solution where their growth could be observed under a microscope. Ten years later these cells were growing as rapidly as when first isolated, each mass generally doubling its volume in two days. If it had been

practicable to furnish suitable conditions for all of the cells which have been formed since 1912, the total mass today would be greater than that of the sun. These cells have now passed through nearly 19,000 generations. Under these experimental conditions the cells have not developed into the adult heart cells, but have continued young indefinitely. These illustrations serve to emphasize the distinction between the life of the organism and the life of the cell. They explain why it is necessary to apply definite chemical agents to kill the individual cells in an animal, before they can be properly stained. In the preparation of cells for microscopic study several distinct processes are employed, usually in the following order: (1) Killing and fixing all of the parts of the organ in as normal a relation and shape as possible. (2) Hardening the many parts so that they will retain

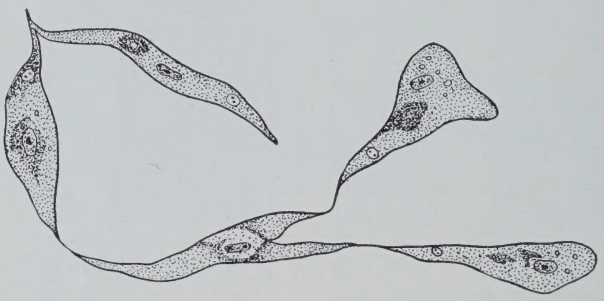


FIG. 32.—Heart-muscle cells cultivated outside of the body of the embryo chick which were observed through the microscope and seen growing, three uniting with one another and finally contracting in unison. (Redrawn from Tower and Herm, Am. Mus. Jour., 1916, **16**, 473.)

their characteristic outline. (3) The staining of all the parts so as to differentiate them as a result of their different reactions to stain. It requires much skill to be able to secure the best possible results in the use of the many stains now employed. (4) The parts of the organ must be cut into thin, nearly transparent sections if the microscope is to be employed in studying them. Every one of these several processes requires much detailed technical work, each step of which must be accurately done or the result is a failure. The science of histology is very technical, although fundamental to the study of embryology, pathology and bacteriology. The present chapter aims to serve as an introduction to the histological analysis of an organ.

Free cells can be seen in complex animals in the blood only, although the ova and spermotozoa are also independent. All the remaining

cells in the higher organisms are joined into layers, or united into muscles, or form a compact skeleton. In the plants all of the cells except the reproductive are joined to one another. Just what shape each group of cells takes depends on its position in the organism and its physiological responsibility. Primarily one thinks of cells as round like ova but pressure from adjacent cells and the nature of the cell membrane results in many different forms. Each cell that manufactures an enzyme or assists in moving the body or affords support has peculiarities that have become constant. It is such facts as these that enable the biologists to classify animal cells into four elementary tissues. *A tissue is a group of similar cells having a similar function.* There are more than four tissues in the frog but not more than four that are elementary. Each becomes differentiated into several special kinds and some give rise to special organs like the glands. These four are (1) epithelial; (2) supporting or connective; (3) muscular; (4) nervous.

1. **Epithelial Tissues.**—The epithelial tissues are the oldest and the first to appear in the embryonic development. They have undergone but little modification in order to perform their several functions. These tissues are found in the skin of the frog, lining the mouth and entire digestive canal, lining the lungs and ducts of the entire excretory and reproductive systems. They also constitute the glandular cells in the liver, pancreas, kidneys, ovaries and testes of the frog. Their most important work is to form a protective covering to surfaces, both exterior and interior, to avoid drying, to act as a buffer against mechanical injury, and to prevent infection by disease germs. Their very position makes them the most important structures in secretion and excretion of glands (Figs. 34 to 36) and in receiving stimuli from the external world. Epithelial tissue is subdivided into (*a*) flattened or squamous (Fig. 33); (*b*) columnar (Fig. 35); (*c*) ciliated (Fig. 34). Epithelial tissue has a small amount of intercellular substance. In the skin, cornea of the eye and some other regions, several layers of epithelial cells are found and such an arrangement is termed a stratified epithelium. Bloodvessels do not penetrate epithelial layers so that all food has

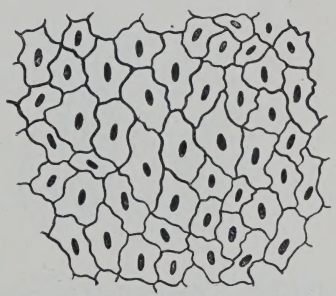


FIG. 33.—Squamous epithelium from the mesentery of the frog.

to pass into them by osmosis. Epithelial cells are easily modified resulting in hair, nails, teeth, horns and glands. The glands of the frog consist of two general classes, defined as unicellular and multicellular. In the unicellular gland a single epithelial cell takes on the function of producing a secretion (Fig. 34 and 35). Multicellular glands involve a number of epithelial cells that may undergo considerable change in shape. The two main kinds of multicellular glands are the tubular and acinous (Fig. 36).

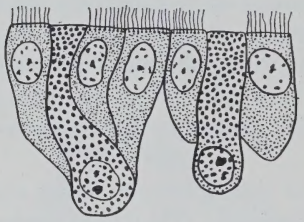


FIG. 34.—Ciliated epithelial cells from the roof of the mouth of the frog. Note the two unicellular gland cells packed with coarse granules.

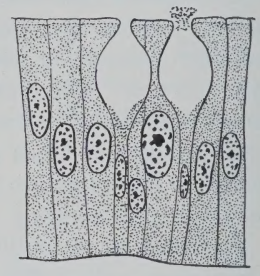
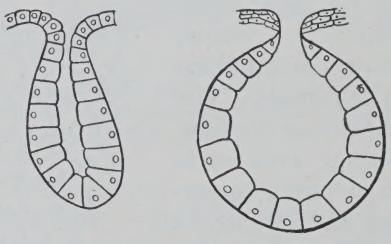


FIG. 35.—Columnar cells from the lining epithelium of the small intestine of the frog. Two unicellular gland cells are also shown.



A *B*

FIG. 36.—*A*, tubular gland from tongue of frog; *B*, acinous gland from skin of frog.

2. **Connective Tissues.**—This group embraces a large number of tissues whose main function is to bind the parts of the organism together, to give a support and to furnish an attachment for muscles. They are always found in the deep parts of the body and gain their chief importance through the intercellular substance produced by them. The cells of connective tissue are inconspicuous and largely remain in their embryonic state. Bloodvessels and nerves pass freely among the cells. Fat and pigment are stored in certain of these cells. Connective tissue cells produce fibers, cartilage, and bone.

(Figs. 37 and 39). In each of these three the cells become inconspicuous. This is especially true where the fibers unite to form a tendon and in bone. By some the blood is regarded as a modified form of connective tissue, the plasma being regarded as the intercellular substance and the corpuscles the living part of the tissue; others regard the blood as simply a nutritive fluid of which there are two kinds: (*a*) the blood proper and (*b*) the lymph.

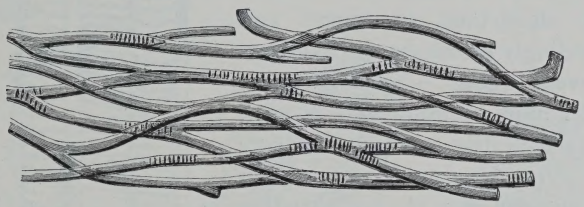


FIG. 37.—Elastic fibers from the ligamentum nuchæ of the ox, showing transverse markings of the fibers. (Schäfer.)

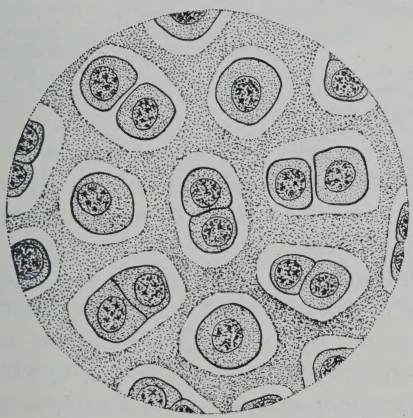


FIG. 38.—Cartilage from the sternum of the frog. Notice the large amount of intercellular substance shown by "stippling," which is one of the important points to consider.

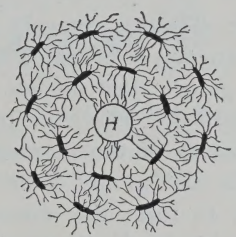


FIG. 39.—Diagram of finer structure of bone. *H*, Haversian canal. The intercellular substance is represented by the uncolored areas between the oval black area and their branches.

3. **Muscular Tissues.**—Muscle cells are recognized apart from all other cells in the frog by the specialization that has taken place in the cytoplasm. As is well known, muscles are divided into voluntary and involuntary. The cytoplasm in the cells of each kind becomes modified so that there results a rapid contraction in the voluntary and a slow contraction in the involuntary muscles. The involuntary

muscle cell has undergone but a small amount of change (Fig. 40); while the voluntary cell is greatly elongated, has special bodies which give a cross-striated appearance and there is more than one nucleus for each cell (Fig. 41). The term sarcoplasm is given to the cytoplasm of muscle cells. Muscular tissues are also sharply distinguished from all other tissues by their function. Muscle cells work by shortening in length and correspondingly increasing in diameter.

4. **Nervous Tissue.**—Nervous tissue serves to conduct stimuli and as such must connect the sensory surfaces with the central nervous system, and also the muscles with the coördinating

FIG. 40.—Involuntary muscle cells from the stomach of a frog.

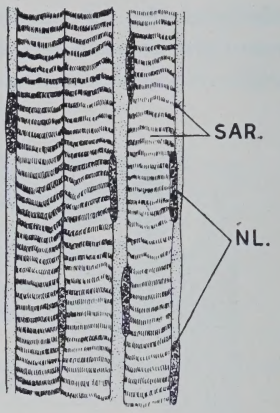


FIG. 41.—Voluntary muscle cells from the fish *Amia calva*. Notice the narrow layer of unmodified cytoplasm. *NL.*, nucleus; *SAR.*, sarcoplasm.

center. The cell elements are ganglion cells and their nerve fibers. The ganglion cells are confined to the central nervous system or to small ganglia just outside this system. The nerve fibers are naked or sheathed. (Discussed in detail in Chapter VI).

Histology of the Stomach or Intestine.—A single tissue does not exist as such in any of the higher organisms but several of them are united to form the stomach, tongue, or liver. This grouping of tissues into such structures gives rise to organs, one of which we will analyze. The stomach is an organ composed of tissues that belong to each of the four elementary tissue groups. On the outer surface there is an epithelium; while columnar epithelial cells line the inner surface. From some of these columnar cells the gastric glands develop (Fig. 42).

Next to the protective epithelium in the outer surface are two muscular layers, the first having its cells running lengthwise, while in the second the cells extend around, thus giving the names longitudinal and circular muscular layers. Between the inner muscular layer and the columnar epithelial layer, better known as the *mucosa*, is the connective tissue usually termed the *submucosa layer*. The

nerves of the alimentary canal require special stains so will not be seen in your study.

In a similar fashion all of the organs of the frog or man can be analyzed and in each the structural unit is the cell. No one pretends to explain why the cell is the ultimate vital unit of organisms. We accept this as one of the basal facts of biology. No student of life can either appreciate or understand life until he studies these units and recognizes their importance in all modern explanations of biological phenomena.

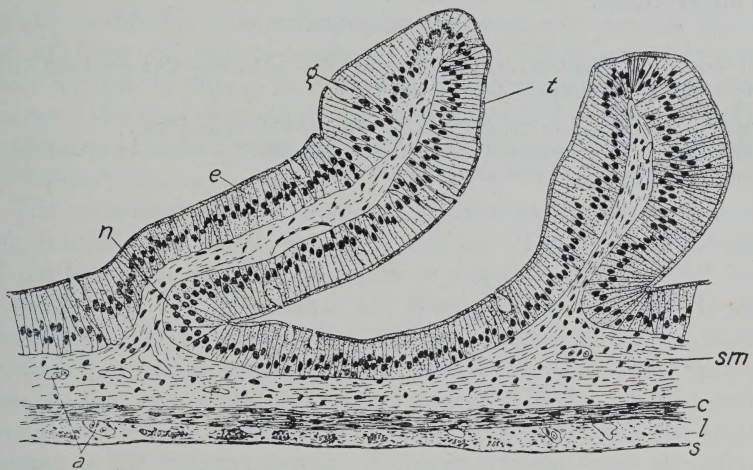


FIG. 42.—Transverse section through the intestinal wall of *Cryptobranchus* to show the details of two longitudinal folds. *a*, bloodvessels; *c*, circular muscle layer; *e*, columnar epithelium forming the layer; *g*, goblet cells; *l*, longitudinal muscle layer; *n*, group of young cells; *s*, serosa; *sm*, submucosa; *t*, top-plate or striated border. (Reese.)

The historical progress of biological knowledge has been traced now from the origin of taxonomy through comparative morphology and physiology, to the finer analysis of organs into their constituent tissues and cells. In passing through these great stages in the growth of accurate and lasting information about living things, you have been repeating in a general way the methods of the great thinkers and workers in the science of biology. You have been making observations about the structure and use of the many parts of a complex organism. This has been done in an orderly fashion and your information about them has been grouped or classified. You can already draw some conclusions from these studies about life. When you follow such an orderly process in your work, you are said to be using

the scientific method. The importance of this method will be emphasized later.

Although we have come by these rapid strides to the modern point of view in biology, we are far from having a complete explanation of the life of living things. In a later chapter we shall try to carry the analysis into the organization of protoplasm which will reveal some additional relations but still does not furnish a complete explanation. But before this is undertaken we shall study two additional organ systems in the frog and indicate how their analysis contributes to life processes.

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HOLMES: Biology of the Frog, Chapter VI.
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SHULL: Principles of Biology, pages 109–114.

CHAPTER VI.

NERVOUS SYSTEM OF THE FROG.

THE nervous system is just like all other organs in the frog in that all of its parts consist of cells. But these cells have become very greatly modified in most instances for the purpose of carrying stimuli quickly from one place to another in the body which makes the complete analysis of this system beyond the scope of an introductory course. We shall first study the nervous system as did the earlier anatomists a hundred years ago, then try to discover what some of the special parts do.

The nervous system is composed of three well-known divisions: the central, peripheral and sympathetic. The central consists of the brain and spinal cord, which is protected by the skull and vertebræ and two membranes, the dura and pia mater. To the peripheral division belong all of the nerves arising from the brain, termed the cranial nerves and the spinal nerves. These nerves pass to the skin, sense organs and muscles. There are two main trunks of the sympathetic system which lie just beneath the spinal column in the cœlomic cavity. As these branches cross the spinal nerves there is formed a connection with a slight ganglionic enlargement (Fig. 43). The sympathetic nerves branch profusely in connection with the viscera, forming several plexuses (solar, urogenital, etc.). The brain and spinal cord form the most important of these three divisions, for to it all general stimulations report and from it all commands are issued.

The gross study of this region reveals a short and somewhat flattened spinal cord with two swellings; the first opposite the arms and the second opposite the hip region. Fig. 43 explains why these two regions are enlarged; from each large nerves pass off. Posteriorly the spinal cord ends in a small point (the filum terminale). Anteriorly the spinal cord merges into the brain without any sharp demarcation. The brain is subdivided into the following, beginning from behind: the medulla oblongata, the cerebellum, the midbrain, the thalamencephalon, the cerebral hemispheres and the olfactory lobes (Figs. 44 and 45).

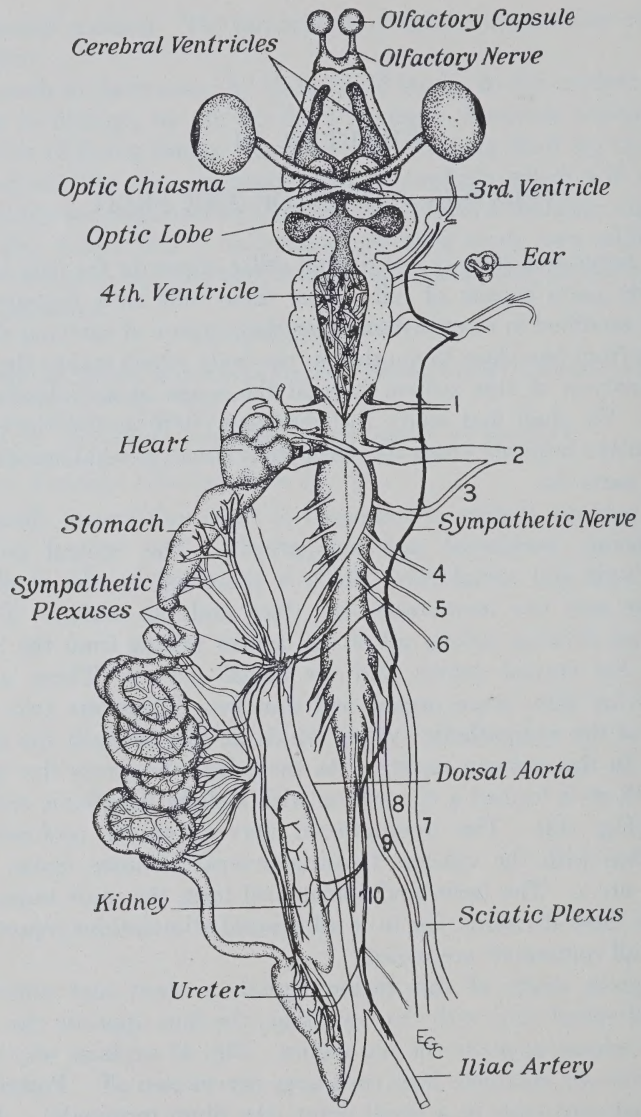


FIG. 43.—Ventral view of nervous system of the toad. The sympathetic nervous system is drawn in solid black lines. Note its relation to the spinal nerves and visceral organs. The floor of the brain has been removed so as to show the ventricles of the brain. Observe the relation that each of the sense organs has to the brain. The eighth nerve is connected with the ear, which is closer to the brain than in the drawing.

The medulla is recognized by the large opening on the dorsal side, the fourth ventricle. This opening is roofed by a non-nervous tissue richly supplied with bloodvessels and termed the posterior choroid plexus (*mtplx.*, Fig. 44). From the sides of the medulla arise five pairs of cranial nerves and from its floor one pair of eye-muscle

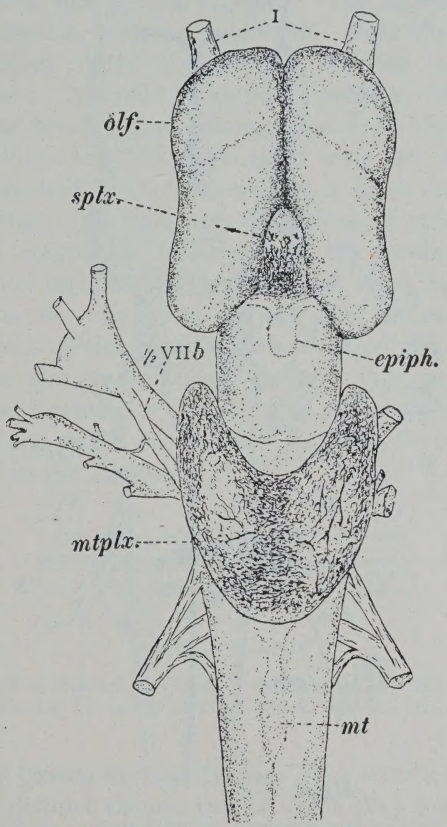


FIG. 44.—The brain of *Necturus maculatus*, dorsal aspect. × 5.4. *olf.*, olfactory portion of cerebral hemisphere; *splx.*, supraplexus; *epiph.*, epiphysis; *mtplx.*, metaplexus; *mt*, metatela. (Kingsbury.)

nerves. The nerves from this short and insignificant appearing section of the brain regulate the heart in part, respiration, taste, hearing and the general muscles and special senses of the head other than seeing. Immediately in front of the medulla is the small transverse fold, the cerebellum, which becomes much larger in the higher vertebrates.

The roots of one pair of eye-muscle nerves are located in it. The dorsal surface of the midbrain is made prominent by the large oval masses, the optic lobes, (rudimentary in *Necturus*, Fig. 44). The shortest and most inconspicuous section of the brain is the

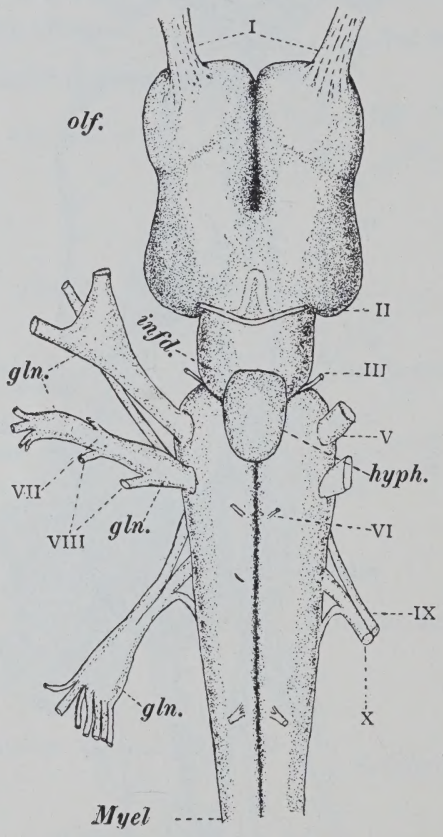


FIG. 45.—Brain of *Necturus maculatus*, ventral aspect. × 5.4. *gln.*, ganglion, *hyph.*, hypophysis; *infd.*, infundibulum; *Myel*, spinal cord; *olf.*, olfactory portion of cerebral hemisphere; *I* to *X*, cranial nerves. (Kingsbury.)

thalamencephalon. Its roof is non-nervous and contains numerous bloodvessels, and hence the term anterior choroid plexus is appropriate (*splx.*, Fig. 44). From the roof arises the pineal body (*epiph.*, Fig. 44), the remnant of a median eye. This rudimentary organ is one of the endocrine glands and has an influence on the early development of all vertebrates. On the floor of this region is located

the prominent crossing of the optic nerves (II, Fig. 45) called the optic chiasma. Posterior to the optic chiasma is seen a tubular enlargement, the infundibular lobe, partly nervous and partly glandular (*infd.* and *hyph.*, Fig. 45). This small structure of the brain is also an endocrine gland and bears a most important relation to normal growth and certain diseases. The cerebral hemispheres are elongated bodies, tapering anteriorly. Near the anterior end a slight constriction marks the division between the cerebral and olfactory regions. It should be noticed that the olfactory lobes lie anterior and not beneath the cerebral lobes, as in higher vertebrates. The cerebral lobes are entirely isolated from the sense organ and the organs of the body. No nerves enter or leave them. Therefore all nerve impulses must first pass through some other region of the brain and all commands issuing from the cerebrum must pass through a second region of the brain before reaching their destination. There is no way of measuring the influence that these associated regions of the brain may have upon the nerve impulses that start from the cerebral hemispheres. This important fact is equally as true for man as for the frog. The distribution of the several cranial and spinal nerves and the sympathetic system should be determined in the laboratory.

FIG. 46.—Diagram through the head of the frog to show the relation of the internal ear to the skull (in black) and the brain.

Tissues in the Central Nervous System.—The nervous system is composed of three distinct tissues, two of which play a minor, although essential, part in the work of the whole system. These minor tissues are the connective and the blood tissue; the former supply the protective sheaths and supporting framework, while the latter carry food to all parts and remove the wastes of metabolism. While these two tissues are everywhere present, yet they occupy but a relatively small part of the nervous system. The third tissue is the nervous, which represents the most highly specialized cells found in any tissue. Pure nerve tissue such as exists for epithelium is not found in the frog, for the nerve cells rarely join and always have in the frog

protective and connective cells that bind them together. Again, a pure nerve tissue would be of no service to the frog unless the nerves were connected with the skin, muscles, etc.

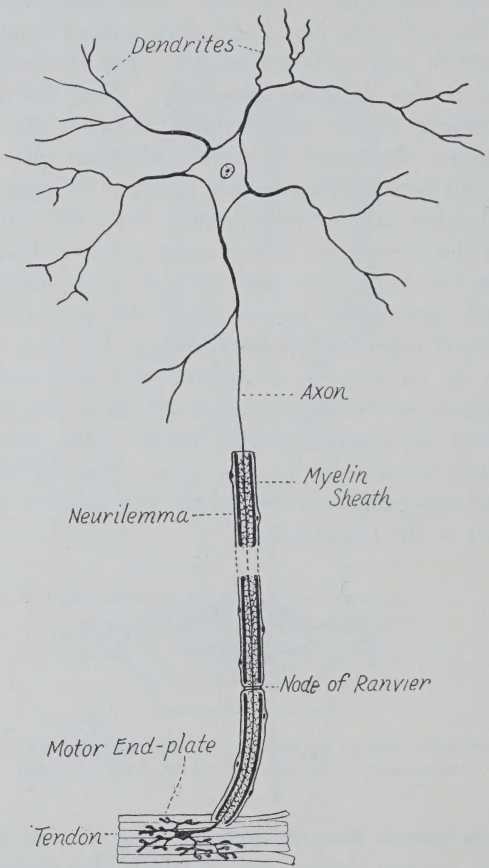


FIG. 47.—Motor neuron or effector nerve cell of *Rana pipiens*.

Neuron.—In order to understand the histology of any region of the central nervous system the nerve cell must be studied.

Neuron { Cell body { Cytoplasm processes { Dendrites / Neurite, axon or axis-cylinder } / Nucleus }

This diagram and Fig. 47 will help to make clear the several parts in this cell which has become so highly specialized. The term neuron

is given to the entire nerve cell, which is to be regarded as a unit of structure. The cell body is much like other cells, varying in shape and size, but has in addition outgrowths from the cytoplasm which are given the general name of processes and are divided into two kinds, dendrite and neurite. It is the processes that indicate the extent of specialization that has taken place in nervous tissue as compared, for example, with epithelial tissue. The large cells in the ventral region of the gray substance of the spinal cord as seen in the laboratory have several short processes that are branches; these are the dendritic processes (Fig. 47). Each of these cells is somewhat conical, and from the point a slender non-branching process arises which can be traced but a short distance; this is the neurite or axon. By the

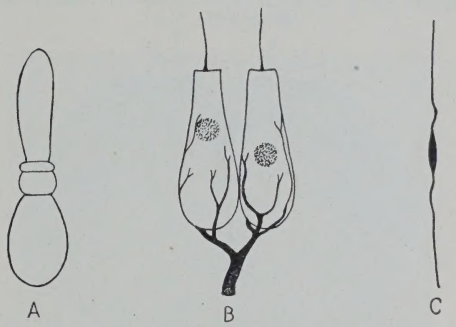


FIG. 48.—Three types of sensory neurons or receptor nerve cells. *A*, retinal rod from the retina of necturus and stimulated by light waves; *B*, modified ciliated epithelial cells from the lateral line sense organs of squalus acanthias. These cells are stimulated by low vibrations similar to sound waves. Redrawn from Johnston; *C*, neuro-epithelial cell from the nasal cavity of an embryo turtle. This cell sends its own axon to the brain.

use of special nerve stains the axon of these cells can be traced out into the nerve roots that arise from the ventral region of the cord. This axon continues in the nerve to end finally in some muscle. Thus the axons that pass to the hind feet might be six inches long in a large frog, which would make the total bulk of the axon many times that of the cell body which produced it.

The neuron just described is one of the most highly specialized cells found in the body of the frog. Some of the neurons are simple epithelial cells specialized to receive some form of physical or chemical stimulus. The neurons shown in Fig. 48 are readily recognized as simple cells, yet each is specialized to receive a given stimulus only. When these receptors are concentrated into a single structure, we have a highly specialized sense organ as the eye, or ear; when they

are more loosely grouped such a one, as the olfactory organ or the tongue; or the receptors may be free nerve endings as in the skin, intestine, muscle or gland. In this latter instance, the sense organ is very simple and the information derived equally simple and general. The kind of stimuli that each of these several receptors responds to is specific for each. A stimulus means really some change rather than a continued environmental condition. Such shifting of the outward changes tests the animal's capacity for reaction. Within the brain and spinal cord is found a third type of neuron that simply conducts stimuli from one region to another. These are the association neurons, and they are very numerous. The thousands of neurons in the nervous system of the

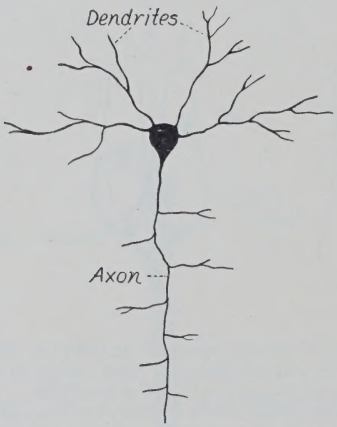


FIG. 49.—Association nerve cell. This class of nerve cells lies wholly within the central nervous system. From the cerebrum of the rabbit.

frog are arranged into three classes: (1) The sense organs or receptors; (2) association neurons; (3) those that carry stimuli directly to the muscles, glands, etc. The muscles and glands are known as effectors and the neuron which stimulates such structures is often designated an activator.

Origin of Processes.—The nerve cells arise in the embryo as rather regular columnar epithelial cells, with an entire absence of processes. As the embryo frog develops small outgrowths arise on the cells that are to become processes. These continue to grow, deriving their growing energy from the cell body. As they first arise they are naked processes, many of which remain as such throughout the life of the frog; but part of them become surrounded by well-

defined, thick, fatty sheaths, the medullary sheaths, which are secreted by the processes which are thus enveloped.

Histology of the Spinal Cord.—An analysis of the finer structure of the spinal cord will serve to illustrate the complexity of this highly specialized organ and give some insight into the way it works. The whole spinal cord is enclosed in a strongly protective membrane, the pia mater. Within the pia mater the cord is constricted on the dorsal and ventral surfaces. These constrictions are the dorsal and ventral sulci (posterior and anterior fissures of human anatomy). The area of the cord when seen cut in cross-section is made up of a peripheral layer of white substance in a fresh section, the white appearance being due to the fat in the medullary sheaths of the axons in this region and of the central area of gray substance. In the

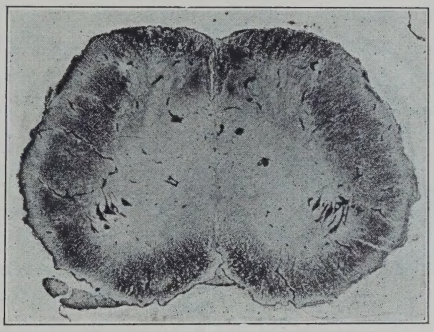


FIG. 50.—Photomicrograph of spinal cord of *Rana pipiens*. The motor nerve cells are stained black.

regions where the spinal nerves arise the gray substance extends in strands to the surface of the cord. This gives to the gray substance much the shape of an expanded butterfly. The white substance of the cord is occupied mostly by medullated nerves running longitudinally, while the gray substance is composed of numerous nerve cells and their unsheated processes. The center of the gray substance is occupied by a small cavity, the neurocele, which is surrounded by epithelial cells, the bases of which can be traced far out into the substance of the cord. This central nervous cavity extends throughout the length of the central nervous system and becomes expanded in the brain into the four ventricles (Fig. 43). At certain definite places the nerve fibers in the cord cross (Fig. 51). Here and there in any section of the spinal cord bits of capillaries show with their contained blood corpuscles.

Nerves.—Between the segments of the spinal column, pairs of spinal nerves pass off from the cord. Each nerve arises by two roots from the cord: one from the dorsal region and one from the ventral. On the dorsal root there is a small enlargement that contains many cell bodies which give origin to nerve processes. The presence of these nerve cells on the dorsal root distinguishes the two roots as to form as well as to function. The ventral root is mostly made up of fibers which grow out from the large cells in the ventral region of the gray substance and most of them end in some muscle. This means that the nerve stimulus travels outward and away from the spinal cord over these fibers. This also means that these fibers cannot be stimulated normally except through the spinal cord. The term motor or efferent is given to the ventral root. The

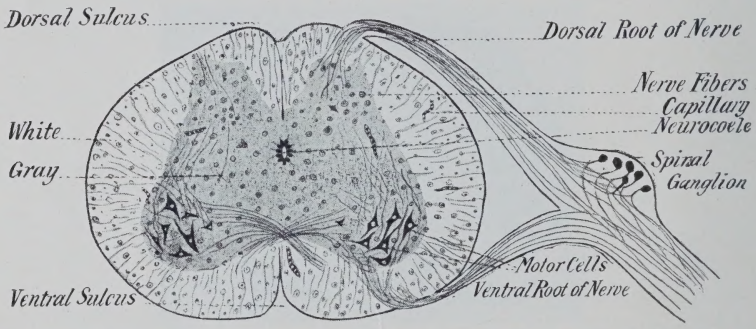


FIG. 51.—Diagram of spinal cord of frog.

dorsal root consists exclusively of fibers which arise from the cells in the dorsal ganglion. Part of these fibers pass out into a nerve and are enclosed in the same general sheath with those from the ventral root for a part of the way. The dorsal root fibers end in the skin.[1] From the same dorsal ganglion cells fibers grow into the spinal cord and send branches in several well-known directions. The normal stimulus for the dorsal root fibers is something that reacts on the fiber ending in the skin. Such a nerve impulse is carried to the spinal cord, where it is interpreted usually through the assistance of the brain, and the resulting explanation is sent out over the motor fibers to the muscles. The dorsal root, then, is known as the sensory or afferent root. Such is the structural plan of each spinal nerve.

[1] No attempt is made in this elementary book to present the functional divisions of the dorsal and ventral roots.

The nerves that arise from the brain have lost some of their primitive parts and each must be studied separately. Within the central nervous system there are many definite paths over which certain nerve impulses travel, but their study belongs to a course in neurology.

Stimulation of Nerves.—The most conspicuous feature of the nervous system is its power of responding to light, heat, touch, sound, etc., that is, to a stimulus. This power of being aware of the various stimuli is based upon a fundamental characteristic of protoplasm known in biology by the name of irritability. Originally all of the cells possessed this property, but as they grew into bone, muscle, etc., there was no need for irritability and it remained undeveloped. But irritability is only part of the work of responding to a stimulus, the light or heat stimulus is conducted along the nerves to the central nervous system. Here it is interpreted and the frog acts according to the nature of the stimulus. For the frog to respond to a stimulus involves the use of three highly developed fundamental protoplasmic properties, *i. e.*, irritability, conductivity and coördination. These three processes, then, are at work in every nervous response of the frog.

Reflex Action.—The simplest form of a reflex arc is where the stimulus acts on the sensory neuron and this in turn transmits the stimulus to a motor neuron which then causes a muscle to contract. In the frog there are usually several associational neurons in between the sensory and motor neurons. The simplest reflex arcs occur only in very simple animals.

In order that a stimulus may pass from one neuron to another, there must be a junction between the two. Such a relation is called a *synapse*. While nerve fibers transmit stimuli in both directions, the synapse does not. The ease with which a stimulus passes the synapse varies, as is shown by the influence of such stimulants as coffee or strychnine which make it easier to cause a reaction. Depressants like alcohol or ether suppress the reflexes. It is believed that these changes are most marked at the synapse. A reflex act then involves the response of the frog to a stimulus outside of the central nervous system. This response takes place without the influence of the brain as is proved by the familiar experiment of destroying the brain, and then applying a drop of acetic acid to the skin in the region of the back. The feet move to the irritated region, scratching to remove the stimulant. The spinal cord regulates a number of the activities of the frog, especially in the visceral organs and these are all known as reflex

actions. Reflex acts are usually coördinated, which means that they combine for a common end. Reflex acts constitute the oldest responses of an animal and were determined by the organization of the nervous system and the animal's environment. We shall now see how an ancient reflex act was the source of a new habit.

Habit Formation in Frogs. —"July 29, I placed 30 of the hairy caterpillars in the cage. *Rana sylvatica* attempted to eat a caterpillar seven different times within an hour but rejected it each time. Following these trials no other caterpillars were visibly reacted to. By attempting to eat a caterpillar and then rejecting it is meant this: The frog shot out the tongue in the normal manner, bringing the caterpillar back to the mouth (an old reflex act), then extruding the tongue slowly, slightly wriggling it. In most cases this muscular wriggling freed the caterpillar from the tongue; if it did not the withdrawal of the tongue into the mouth scraped off the caterpillar in nearly every case." On August 9, 12.30 P.M., "The caterpillar was placed in the cage again, *Rana sylvatica* reacted first by making two short hops to orient so as to look directly at the caterpillar. (The caterpillar was about 5 cm. in front of the frog.) The head of the frog was then slowly lowered and brought forward toward the caterpillar, but I could not see that the tongue was shot out, although I watched especially to see if this would happen. In a second or two the head lurched forward a little more and then the tongue was very slowly extended, barely touching the caterpillar. The tongue was now withdrawn and then suddenly extruded, with what appeared as a very slight attempt to shake the caterpillar off. The caterpillar elicited no further response during the next forty-five minutes." For four days the frogs were scantily fed and then a caterpillar was put in the cage. *Rana sylvatica* took no notice of it. *Rana sylvatica* formed the habit of avoiding hairy caterpillars in seven trials.[1]

In the nervous system we have studied the most highly specialized tissue in the frog. The cells possess long processes that transmit stimuli to the spinal cord and brain and out to the muscles and glands. The simplest form of nervous reaction is a reflex act which may involve only a sensory and motor nerve, although there are usually some associational neurons in a reflex arc in the frog. Specialized epithelial cells and free nerve endings respond to specific environmental changes. There are highly

[1] Schaeffer: Habit Formation in Frogs, Jour. Animal Behavior, 1911, No. 5.

developed sense organs such as the eye or ear through which information of distant objects reaches the nervous system; or such simple organs as the olfactory or gustatory which require contact with the object smelled or tasted; and free nerve endings where pressure, heat and cold are the sensations that arise from these simple energy changes.

In addition to furnishing a means of gaining information about the environment and changes within the body, the nervous system thus serves to regulate nearly all of the bodily activities. In recent years it has been proved that endocrine glands share with the nervous system in this regulating control of the body. These glands play a more conspicuous part in the normal growth of the body as it passes from infancy to youth and through adolescence; while the nervous system supervises the environmental responses and reflexly directs nearly all of the visceral activities such as the beating of the heart or the movement of food along the digestive canal. The structural plan of this highly important organ system is a series of cells that communicate with one another through a synapse. These cells are grouped in many ways so that different stimuli follow different routes in the nervous system. The movement of a stimulus along a nerve fiber is accompanied by the formation of carbon dioxide which indicates that metabolic changes are intimately associated with the process of nerve transmission. The formation of carbon dioxide indicates that energy is used when a stimulus travels along a nerve and in this sense, one may say that a nerve works. These highly specialized nerve cells require food for just the same reason that the other cells in the frog require food. Nor do these nerve cells need a special form or kind of food. Their protoplasm is like the protoplasm of epithelial or muscle cells and they expend energy in just the same way. The nerve cells do not possess, then, any unique phases of metabolism so that all attempts to specially feed them fail. On the other hand, the usual procedure has uniformily proved to be the only successful method of properly protecting and nourishing these cells which have diverged so far from the simple typical cell.

In making this simple explanation of the nervous system of the frog, we have found it necessary to take advantage of all of the discoveries that have been made. Passing from the general morphological and physiological descriptions to the minute analysis of nervous tissue into its cellular components, we quickly reach a place where there are unsolved problems such as the passing of

a stimulus in a synapse or the nature of an appropriate muscular or glandular stimulus. Along with these unsolved problems is the significance of the endocrine glands and their part in regulating the bodily activities. This brings us into the field of active research where we must pause until some one is able to learn more about these relations.

Lorsar, Wm.: A Study of the Function of Different Parts of the Frog's Brain, Jour. Comp. Neurol., 1905, vol. **15**.

Wyman, A.: Anatomy of the Nervous System of *Rana Pipiens*, Smithsonian Contributions to Knowledge, 1853, vol. **5**.

Yerkes, R. M.: The Sense of Hearing in Frogs, Jour. Comp. Neurol., 1905, vol. **15**.

CHAPTER VII.

EMBRYOLOGY.

We have learned that energy is necessary for the general metabolic activities of the frog. In all instances this required energy was supplied by food and oxygen. Most of the changes through which this energy passes while in the body of the frog are understood and can be explained. We now pass to

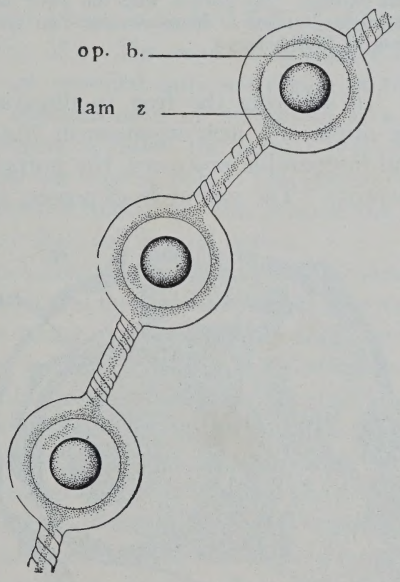


Fig. 52.—Eggs and egg envelopes of *Cryptobranchus*, natural size. *op. b.*, opaque body; *lam. z.*, lamellar zone of the envelope. (B. G. Smith, in Journal of Morphology.)

a more conspicuous use of energy although the same in principle. It is more conspicuous because we can actually observe the increase in bulk. All of the changes that take place in the ovum preparatory to fertilization, all of segmentation, all of the stages in the formation of organs require energy that comes only from the stored up energy in the ovum.

Somatic and Germ Cells.—Until one has actually seen the single-celled ovum change into many cells, elongate, and become a tadpole and finally a frog, the statement that such is the sequence of events

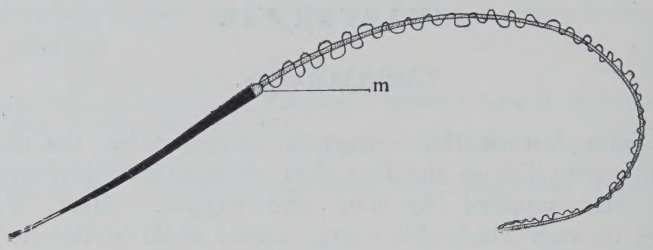


FIG. 53.—This highly specialized cell develops from one that has a nucleus, surrounded by cytoplasm. The conical, dark body is the sperm head and corresponds to the chromatin of the nucleus. The portion with the wavy margin is the tail and is all that remains of the cytoplasm. Spermatozoön. *m*, middle piece. × 500. (B. G. Smith, in Journal of Morphology.)

seems incredible. In selecting the frog to illustrate the principle of growth and the origin of a new organism in Nature, for the two are continuous and inseparable processes, the purpose is to consider it in its broader aspects. The parent frogs possess either spermaries

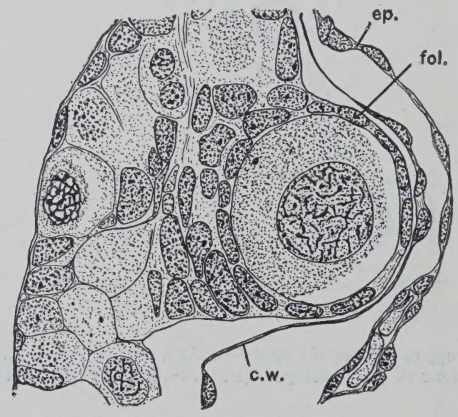


FIG. 54.—The largest cell is the young ovocyte of *Cryptobranchus*. In what particulars is it similar to the other cells in this figure? *ep.*, inner epithelial membrane of the ovarian wall; *fol.*, follicle cell; *c.w.*, cyst wall. (B. G. Smith, in Journal of Morphology.)

in which are produced sperms or ovaries that produce ova. Both sperms and ova are free cells and do not unite to form tissues like epithelium or muscle. This free state is a primitive condition, and if

these cells had some physiological work like digestion to perform, they would be inefficient. But early in the life of the frog the cells which are to be responsible for growing sperms and ova are set apart and never develop into highly specialized adult tissue cells. This gives in each frog one class of cells that continue to grow, eventually becoming highly differentiated. During this growth the cells are specialized and united into definite tissues, which in turn are distributed into complex organs. After such cells have become thus specialized they lose their power to grow new cells other than those like the tissue in which they occur. The general term of somatic is given to all such sterile cells. The sperm and ovum cells are never in their adult form united into tissues and they retain their power to grow new cells. They are called germ cells.

Ova and Sperm Cells.—The ovum of the frog is not a typical germ cell because the cytoplasm is packed full of stored-up food known as deutoplasm (Fig. 55). The result is that most of the cytoplasm and the nucleus are crowded into one region of the ovum. Associated with this concentration of cytoplasm is a black pigment. This pigmented region is called the animal pole of the ovum and the opposite region the vegetal pole. The pigmented area is always uppermost and directed toward the sun because the animal pole is of less specific gravity than the vegetal region.

The highly specialized ovum of the frog represents a cell that started out with a central nucleus surrounded by cytoplasm. During the growth of the young ovum, which is usually termed an ovocyte, there is deposited in the cytoplasm the deutoplasm. Deutoplasm is made by the life processes of the ovocyte and is a product of constructive metabolism. This means that the inert deutoplasm of the frog's ovum must have been living ovocyte protoplasm at one stage. Such stored-up energy is used by the developing embryo.

The sperm cell has departed from the rounded primitive shape for cells and has assumed a highly specialized form. The cytoplasm has become reduced to a very small amount and forms the tail, while the nucleus is concentrated into a solid mass of chromatin, the sperm head. The long vibratile tail assists in the movement necessary to bring the sperm cell to the ovum (Fig. 53).

When the eggs are first extruded they are surrounded by a thin mass of gelatinous substance secreted by the cells in the wall of the oviduct. This may be briefly referred to as jelly. Within one minute after the egg is laid the jelly begins to absorb water. In from ten to fifteen minutes it becomes about six times as thick as

when first brought in contact with the water. As this thickening takes place, definite layers can be made out in it. The jelly serves to unite the eggs in a mass to protect them from mechanical injury and to prevent them from being eaten by microscopic animals. The ova are numerous spherical bodies about 1.75 mm. in diameter. Black in color, they readily absorb heat. The sperms and ova may be frozen without being destroyed if the exposure is short.

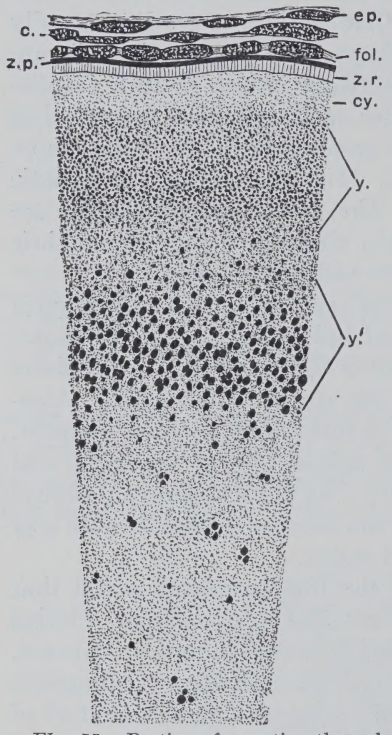


FIG. 55.—Portion of a section through one of the most advanced ovocytes of a 3 5 cm. *Cryptobranchus*, showing the structure of the membranes surrounding the egg and the early formation and distribution of yolk granules (deutoplasm). × 340. *c.*, cyst membrane; *cy.*, yolk-free peripheral zone of cytoplasm; *ep.*, inner epithelial membrane of the ovarian wall; *fol.*, follicular membrane proper; *z.p.*, zona pellucida; *z.r.*, zona radiata; *y.* and *y.'*, layers of fine and coarse granules respectively. (B. G. Smith, in Journal of Morphology.)

Rana catesbiana breeds from June 15 to August 1. The large egg-mass is laid in a short time. The egg-mass has a pancake-like shape from one to three feet across, and in it are found from 12,000 to 20,000 eggs which hatch in from three to five days.

Maturation.—The term maturation is used to describe several important changes that take place in the full-sized egg before fertilization is possible. These changes are mainly limited to the nucleus. The nucleus of the ovum contains too much chromatin and the excess must be removed and forced through the cell wall (vitelline membrane). The process of getting rid of the chromatin consists of a series of detailed changes that are well illustrated in Fig. 58, *B*. In this process there are two general features that may be emphasized: (1) The changes in the chromatin; (2) the method by which the chromatin is removed. The conditions diagrammed in Figs. 59 to 62 illustrate the usual method by means of which the cell divides. It is called the mitotic or indirect method of cell division.

The mechanism for the removal of the excess of chromatin consists in the formation of a temporary structure in the cytoplasm,

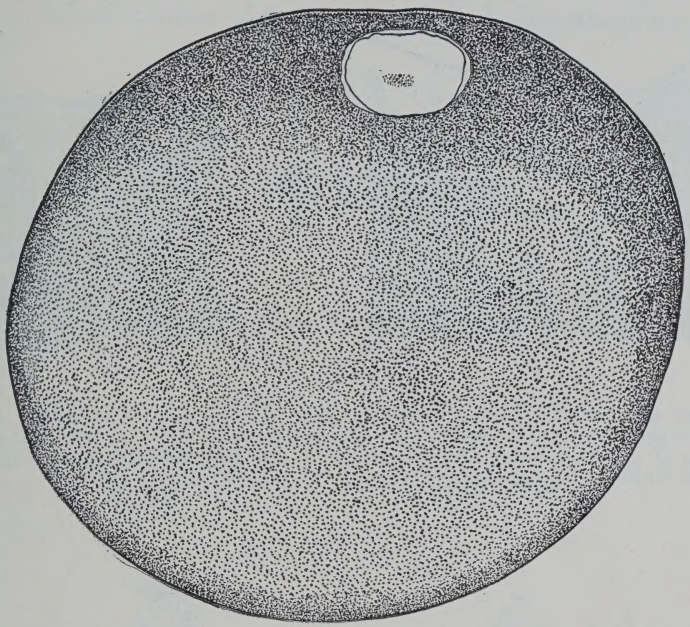


FIG. 56.—Ovarian egg of adult *Cryptobranchus*. *How does this egg differ from the ovocyte? Define growth in terms of the ovocyte and ovum.* (B. G. Smith, in Journal of Morphology.)

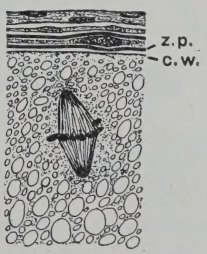


FIG. 57.—Showing first polar spindle of *Cryptobranchus*. *c.w.*, cell wall formed from the zona radiata; *z.p.*, zona pellucida. There are probably six large chromosomes forming a ring surrounding six small chromosomes in a state of division. The chromosomes are the black bodies. (B. G. Smith, in Journal of Morphology.)

the spindle. The exact origin of all of its parts is still a subject of controversy, and they are not the same in all animals. The conditions in the frog are about the same as shown in the illustration for

Cryptobranchus. A spindle arises in the cytoplasm close to the egg nucleus; it is made up of fibers which extend from pole to pole of the spindle as well as fibers which radiate around each pole; these

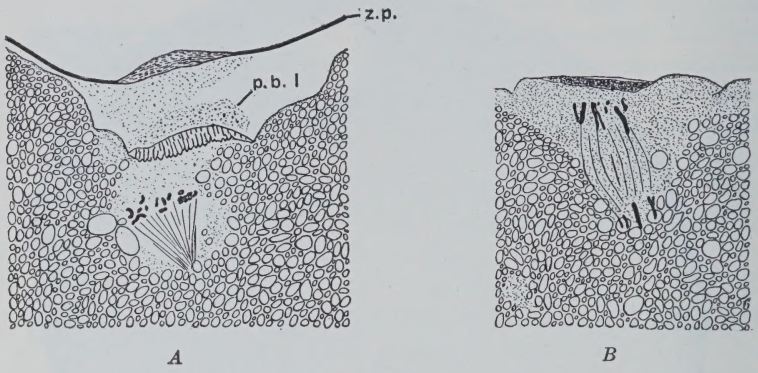


FIG. 58.—Sections showing the second polar spindle, and the formation of the second polar body of the egg nucleus in *Cryptobranchus*. *z.p.*, zona pellucida; *p.b. 1*, debris of the degenerating first polar body; *B*, late anaphase, second polar spindle. (B. G. Smith, in Journal of Morphology.)

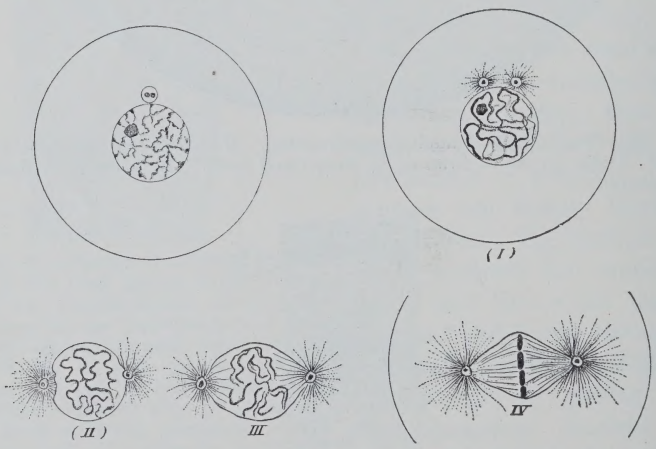


FIG. 59.—Prophases of karyokinesis. *I*, division and migration of centrosome; *II*, resolution of chromatin into well-defined thread; *III*, segmentation of same into chromosomes; *IV*, development of amphiasters; chromosomes equatorial. (Wilson.)

latter are known as the astral fibers (Figs. 59 and 60). The astral fibers terminate in a deeply staining body known as the centrosome. As the spindle grows some of the fibers push their way through the weakening nuclear membrane and come in contact with certain

chromatic masses that have become larger during the time that the spindle was forming in the cytoplasm (Fig. 59, *IV*). These particular chromatin masses continue to enlarge and become organized into a definite number of discrete chromatin bodies which are now

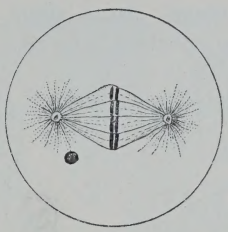


FIG. 60.—Metaphase of karyokinesis. (Wilson.)

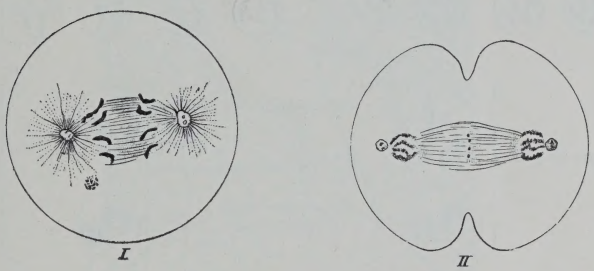


FIG. 61.—Anaphases of karyokinesis. (Wilson.)

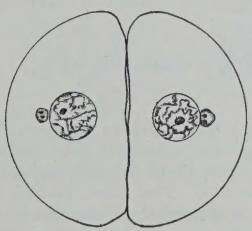


FIG. 62.—Telophase of karyokinesis. (Wilson.)

termed chromosomes. The number of chromosomes in the common toad is 12, in *Rana temporaria* 10 and in *Cryptobranchus* 12, and they are constant for each species.

The chromosomes are drawn into the spindle until they are arranged symmetrically midway between the two poles of the spindle. The growth of the spindle and the increase in size and arrangement of

the chromosomes between the poles of the spindle is a preparatory process and is named the prophase stage. The number of chromosomes and the amount of chromatin is the same in each species.

As soon as the chromosomes take the equatorial position and divide (Fig. 60) it is customary to use the term metaphase in describing this second stage. In a short time the chromosomes divide, each chromosome splitting into two equivalent parts, which

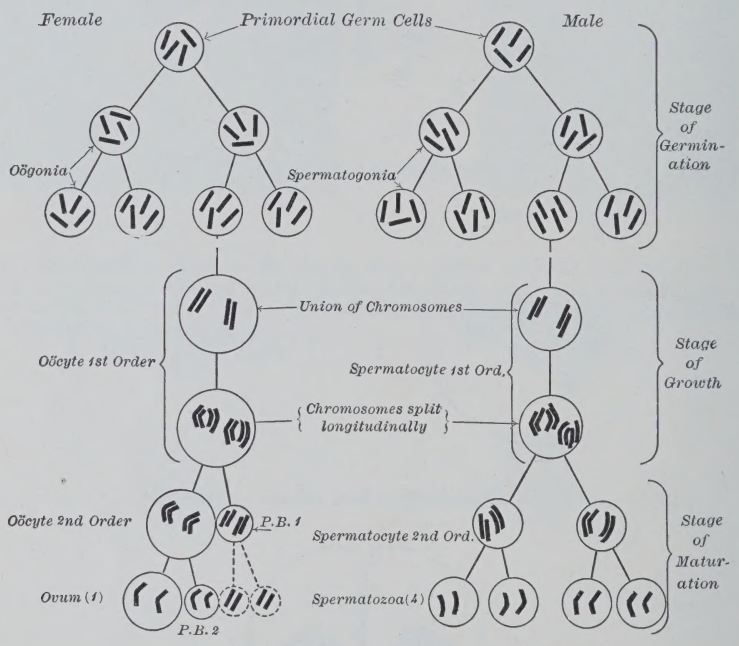


FIG. 63.—Diagram to show the similarity between the maturation of the ovum and the spermatozoön. The two stages of germination and growth are similar. It is not until the final stage that there is a marked difference. In maturation one ovum and four sperms are formed. The polar bodies, *P. B. 1, 2,* do not take part in growth changes and may be regarded as abortive ova.

move toward each pole of the spindle (Figs. 58, *B* and 61). One pole of the spindle moves to the periphery of the ovum, and by the constriction of a small portion of the cytoplasm this distal pole of the spindle and the chromosomes associated with it are cut off from the rest of the ovum (Fig. 58, *A*, *p.b. 1*). The obvious result is that one-half of the original amount of the chromatin in the nucleus has been removed from the ovum. The parts thus removed by this process constitute the first polar cell. The portion of the spindle

remaining in the cytoplasm, except the centrosome, dissolves and is transformed into the cytoplasm. A new spindle arises now under the direction of the old centrosome that remained in the ovum. The work of the new spindle repeats the process already described and there is produced a second polar cell. At the close of the for-

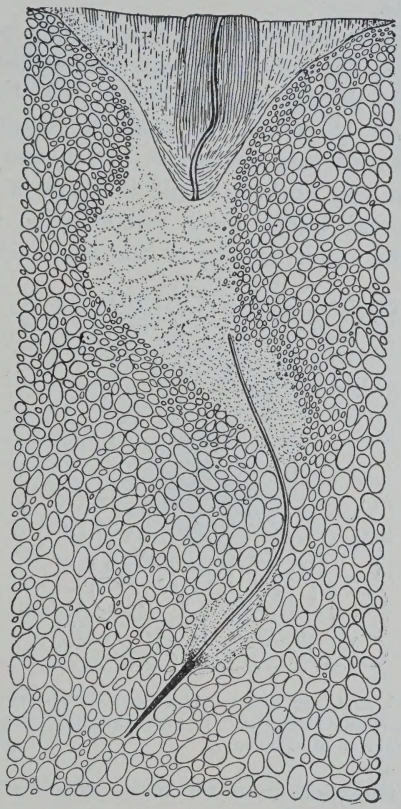


FIG. 64.—Vertical sections of egg of *Cryptobranchus*, showing penetration of the egg by a spermatozoön. × 240. Two and one-half hours after fertilization. (B. G. Smith, in Journal of Morphology.)

mation of the second polar cell the remaining chromosomes gradually become transformed into a nucleus, but a nucleus that has lost three-fourths of its original amount of chromatin. This process is termed maturation and is preparatory to fertilization. The new nucleus is called the *female pronucleus*, to distinguish it from the nucleus of the ovum (Fig. 65). The two polar cells soon disintegrate and play no

further part in development. The first polar cell is formed and the second polar division has reached the metaphase stage by the time the egg enters the lower end of the oviduct. The remaining steps in the formation of the second polar cell usually do not take place until after the eggs have been laid and the sperm has entered the cytoplasm (Fig. 64).

Fertilization.—While maturation is thus taking place the sperm enters the ovum (Fig. 64) and is gradually transformed into a nucleus. This change results through the increase in size of the sperm head, which is nearly all chromatin; it gradually becomes vacuolated and secretes its own nuclear membrane. In appearance this sperm nucleus is like the egg nucleus; while in many instances it is as large, in *Cryptobranchus* it is much smaller (Fig. 65). As a rule one must know the exact history of the two nuclei found in an

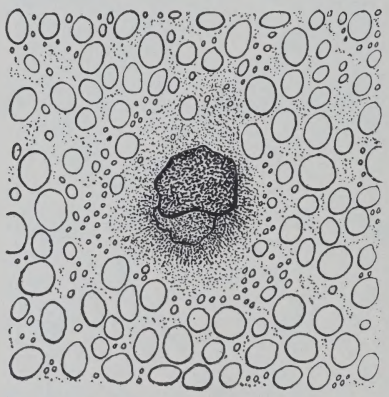


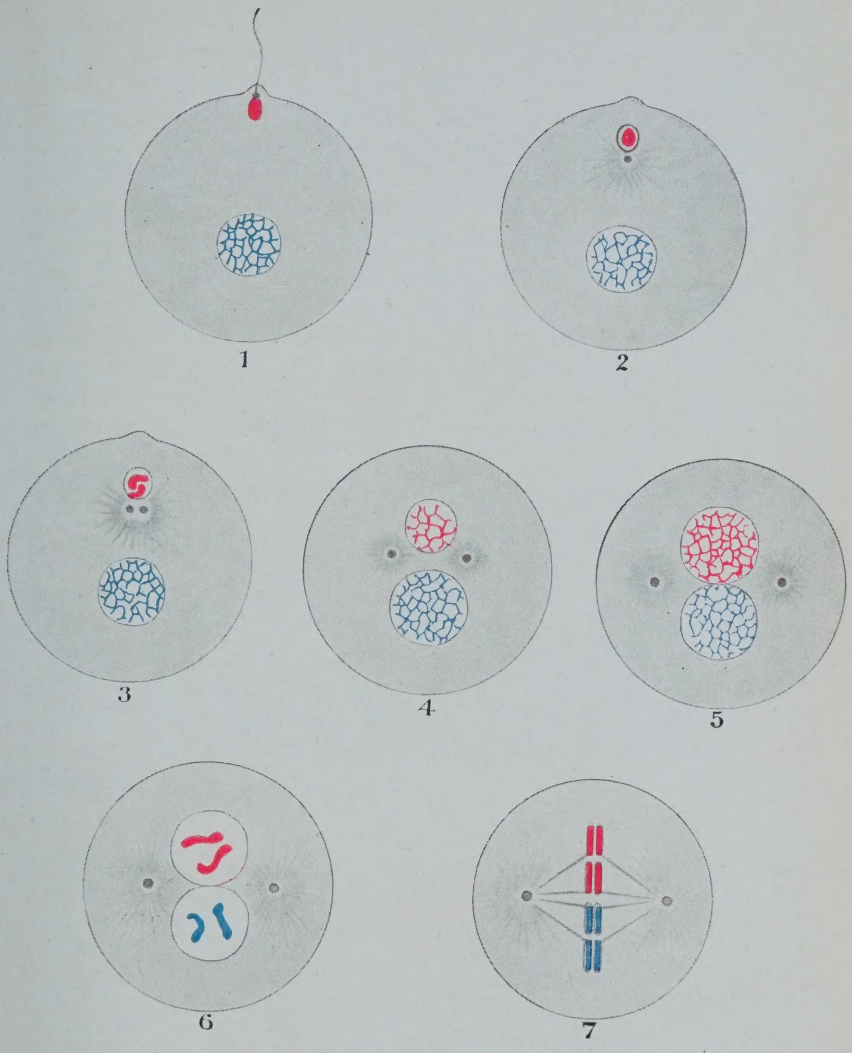
FIG. 65.—Section through egg killed twelve hours after fertilization, showing the fusion of the male and female pronuclei. The male pronucleus is probably the smaller. (B. G. Smith, in Journal of Morphology.)

ovum during fertilization in order to be able to tell their origin, so similar are the two. The male nucleus in the ovum is called the *male pronucleus*.

As the two pronuclei grow to full size the male pronucleus moves through the cytoplasm until it comes in contact with the female pronucleus (Fig. 65). At about this time the nuclear membrane of each begins to break down and the contents of the two pronuclei[1] become enclosed in a single, irregular-shaped nucleus. *This uniting of the two pronuclei is fertilization.* Fertilization takes place outside

[1] For the discussion of the significance of male and female chromosomes, see chapter on Heredity.

PLATE I



Fertilization. (After Adami.)

1. Entry of spermatozoön into ovum. Loss of tail of spermatozoön. 3. Division of centrosome. 4 and 5. Chromatin both of ovum and spermatozoön converted into a network; the two moieties gain approximately equal size. 6. Chromatin of both becomes arranged into chromosomes (one-half of the number of each variety that is usual in the body cells of the species). 7. Formation of spindle; division of chromosome; partition of chromosomes derived from the two parents in equal number between the two future cells (blastomeres).

of the body of the frog. It is difficult to state to just what extent the chromosomes of each pronucleus retain their identity and to what extent they fuse. At any rate the number of chromosomes is not increased by fertilization. This new nucleus resulting from the fusion of the male and female pronuclei is termed the *segmentation nucleus* and the ovum is now properly designated as an embryo.

Segmentation.—After maturation and fertilization the egg begins to show signs of segmentation. The time varies with the temperature, being usually two or three hours after fertilization. Segmentation begins as a vertical furrow in the pigmented region (Fig. 66). This furrow continues until it surrounds the embryo. A division of the nucleus precedes this cytoplasmic segmentation. The result of this constriction is to cut the embryo into two cells. Where the segmentation divisions pass entirely through the embryo it is said to be

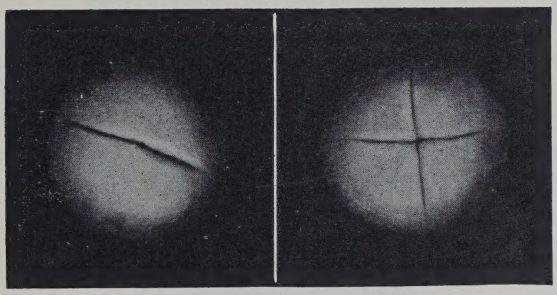


FIG. 66.—Photographs of the first and second cleavage in *Cryptobranchus*, animal pole. (B. G. Smith.)

total. The second segmentation begins about one hour after the first and in a similar manner, but in a vertical plane at right angles to the first (Fig. 66). The third segmentation in the frog is not just like that shown for *Cryptobranchus* (Fig. 67), but is in a horizontal plane at right angles to the first two and a little above the equator of the embryo, which results in producing eight cells, four small ones at the animal pole and four large ones at the vegetal pole. The third division of the embryo results in forming four small cells and four large cells. This cleavage is thus unequal. The first division of the frog embryo illustrates what is meant by total *segmentation* or *cleavage* in the embryonic development of an animal, while the third division is described as unequal segmentation. Segmentation takes place from now on more rapidly at the animal pole and in a short time the cells at the vegetal pole are found to be much larger than those at the

animal pole (Fig. 68). The rate of division is intimately associated with the quantity of yolk present. There are a number of external changes which can readily be observed.

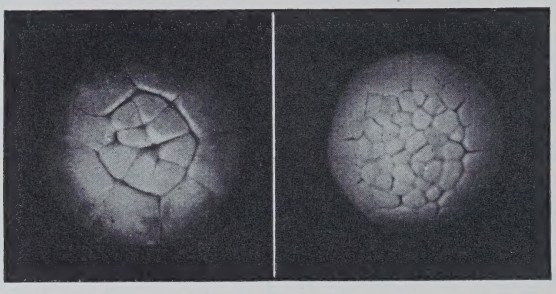


FIG. 67.—Photographs of later cleavage stages in *Cryptobranchus*, animal pole. (B. G. Smith.)

As the cells at the animal pole continue to grow more rapidly than those at the vegetal pole they soon spread over these large cells. This results in forming a layer of small cells which almost completely surrounds the embryo. The term *germ layer* is given to such a layer of cells. As the development continues two more germ layers can

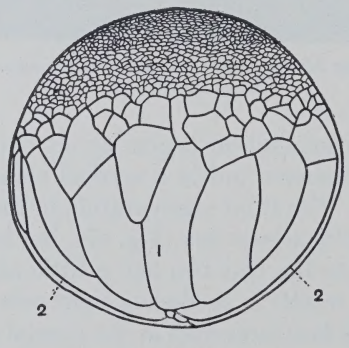


FIG. 68.—Stage nine of the cleavage of *Cryptobranchus*. Equatorial. Note the difference in size of cells at the two poles. (B. G. Smith, in Journal of Morphology.)

be recognized. The one on the outer surface is the ectoderm. The primitive digestive canal is lined with the germ layer known as endoderm; while the third layer is the mesoderm. From these germ layers the organs of the frog are derived.

The ectoderm gives rise to the skin, nervous system, and parts of all of the sense organs, as eyes and ears. The mesoderm forms the muscles, skeleton, blood and bloodvessels, kidneys and reproductive organs. The liver, pancreas and mucosa of the intestinal tract come from the endoderm.

For a considerable time the embryo retains its spherical form (Fig. 68). One of the first changes to be noted is a flattening on the dorsal surface (Fig. 69). A groove soon appears in this region which is the neural groove. The edges of the neural groove unite, enclosing a cavity. This union begins at the anterior end, thus

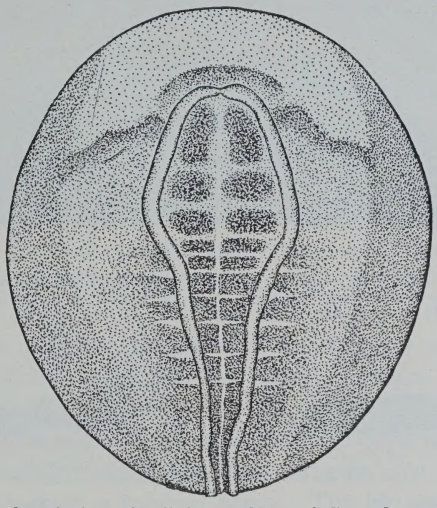


FIG. 69.—Antero-dorsal view of a living embryo of *Cryptobranchus*, viewed mainly by transmitted light, showing neural groove. Free-hand sketch. (B. G. Smith, in Journal of Morphology.)

forming first the forebrain and more posteriorly the spinal cord, both of which are derived from the ectoderm. During this time the embryo has elongated in a direction which marks the longitudinal axis of the animal. The mouth, anal opening, nostrils, gill-slits and sucker appear as the embryo elongates.

Tadpole.—It is from four to five days after hatching before the mouth becomes connected with the remainder of the digestive tube, and during this time the tadpole is dependent for food on the unused yolk (Figs. 70 and 71). The tadpole soon attaches itself by means of its sucker to weeds, etc., and breathes by means of three pairs of external gills. Soon after this stage the mouth becomes connected

FIG. 70

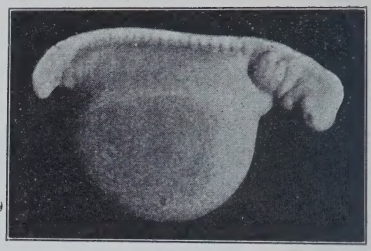


FIG. 71

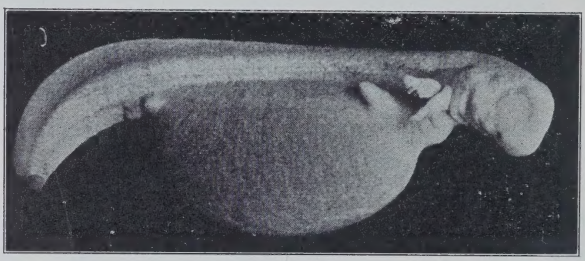


FIG. 72

FIGS. 70, 71 and 72.—Embryos of *Cryptobranchus*, showing the gradual formation of the body and the presence of the yolk. (B. G. Smith, in Journal of Morphology.)

FIG. 73

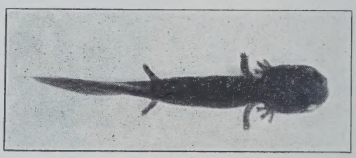


FIG. 74

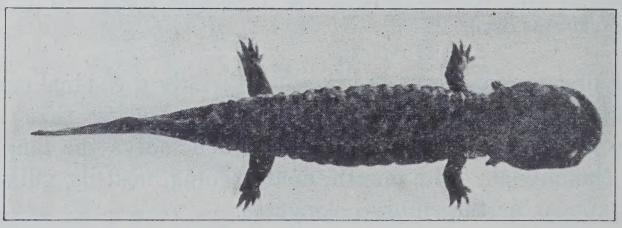


FIG. 75

FIGS. 73, 74 and 75.—Fig. 73, larva of *Cryptobranchus* two months after hatching; Fig. 74, ten weeks after hatching; Fig. 75, larva one year old. The newly hatched larva retains a supply of yolk sufficient to last it from two to four months. Pulmonary respiration is established about five months after the hatching period. The metamorphosis takes place at the end of the second year. Sexual maturity is attained probably at the end of the fourth year. (B. G. Smith, in Journal of Morphology.)

with the digestive tube, the intestine increases greatly in length and becomes much coiled and the tadpole feeds on minute animals. A few days after hatching a fold of skin grows from the side of the head to cover the external gills, leaving a small opening on each side the spiracle, which later closes on the right side, leaving a single spiracular opening on the left side for the exit of water. This fold of skin is the operculum. After the external gills are covered by the operculum they are gradually absorbed and respiration is accomplished by means of the internal gills, which appear about the time that the mouth opens. Up to this time the tadpole is a fish-like animal with a long vertically flattened tail. The muscle segments show on the side of the tail through the skin. *Rana catesbiana* lives for a year in this stage. During the second summer the hind limbs begin to appear as the tail is gradually absorbed, then the front limbs break through the skin and the tadpole becomes a frog. There are important and interesting internal rearrangements accompanying these external changes. The series of changes by which the tadpole is transformed into a frog is known as *metamorphosis*.

Life Cycle.—The study of the frog began with the adult animal composed of organs, tissues and thousands of cells. In the germ glands, eggs or sperms were produced that were set free during the breeding season. These united and an embryo resulted. The embryo underwent a series of segmentation stages which finally resulted in the production of a tadpole. After a time the tadpole transformed into an adult frog. The term life cycle is applied to all of the stages in the life of the frog beginning at any stage and continuing until this stage is reached again. The life cycle of the frog might begin with the adult and include the stages as given at the beginning of this paragraph; or it might begin with the tadpole or any other stage if all of the others are brought into their correct relation to the stage selected.

General Summary of What Has Been Learned About Life in this Study of the Frog.—1. The method used in securing accurate biological information about life consists in making observations in an orderly manner, grouping the facts thus obtained and trying to explain their significance. All the steps in this method which have come to be known as the *scientific method* can be repeated by anyone.

2. The scientific method was applied in the description of the general external features of the frog in which it was possible to recognize that there were several kinds of frogs. In doing this a general notion of the meaning of the term species was obtained. This idea

led to another of larger importance, the relation between the frogs and other amphibians. From this relationship we passed to a larger one, the relation between amphibia and the other vertebrates. The special department of biology which deals with such relationships is known as Taxonomy. Through such a study some insight is gained into the still larger notions of relationship in organisms as one examines the classification of all animals or all plants. The idea that there is a relationship between different animals and different plants is one of the fundamental conceptions of life.

3. We have examined the way in which a complex animal is constituted and have learned something of the extent of differentiation in the several organ systems. This revealed the dependence of these several organs on each other and the general plan on which all vertebrates are organized. This was a study in morphology.

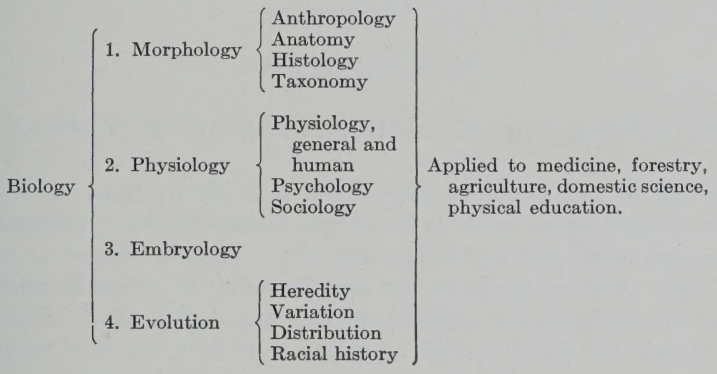
4. As we ventured to explain the use of these morphological structures, it was discovered that an animal keeps its several organs at work by supplying them with energy. This energy is introduced into the body as oxygen or one of the three classes of foods. The frog utilizes energy in its various bodily movements, in the production of heat and in growth. These several manifestations of vital activity are all cared for through the utilization of this energy. An elaborate mechanism has been produced for the digestion, distribution and final utilization of the food, the removal of the wastes, and the responses to environmental changes. Under the caption of physiology are grouped the general dynamic phenomena of the living animal.

5. The gross morphological study of organs did not indicate their composition. Applying modern technical methods, we were able to analyze all of the organs of the frog into tissues and the tissues into cells. The cell is the biologist's unit for this is the simplest structure in which life is known to exist. Modern biological explanations all begin with the cell, whether it is in the use of energy in maintaining life, in explaining disease, in interpretating heredity, or in understanding reproduction.

6. In the study of reproduction in the frog the meaning of organic continuity between successive generations of life was conclusively demonstrated. The association of male and female chromosomes preparatory to segmentation is the time when the new offspring is started on its career to become an independent organism. There is stored in the ovum of the frog a rich amount of energy that is adequate for many important changes such as the growth of a nervous system, digestive canal, glands, muscles and skeletons.

7. The general plan employed in this study of the frog illustrated the main successive steps in the historical development of the science of biology. It is important to remember that each advance was made through the application of a definite plan of procedure and that this is the only successful way to gain reliable information about the biological principles that exist in life.

You have now examined three important subdivisions of the general subject of biology. The fourth, evolution, is deferred until the final section of the book.



PART II.

THE FUNDAMENTAL PRINCIPLES OF BIOLOGY AS ILLUSTRATED BY UNICELLULAR ORGANISMS.

CHAPTER VIII.

PARAMECIUM—AN ANIMAL MADE UP OF A SINGLE CELL.

In our study of the frog the several manifestations of life were examined. Such an animal consists of so many parts that we were able to describe a number of organ systems in this single organism. A marked degree of differentiation was apparent in every structure studied. None of the organ systems could be removed from the body without destroying the life of the frog. This is due to the close interdependence of all of the organs as they unitedly sustain the living organism. Each organ was composed of numerous cells, all doing their specific work. As you analyzed this complex animal, several aspects were emphasized, such as movement, respiration, digestion, excretion, response to changes in the environment, the regulation of the many organs and reproduction. We employ the expression, manifestations of life, for all such vital changes in an organism. If these manifestations of life are the usual criteria of life, then we should find them in every other form of life no matter how complex and large or how small and simple.

Protozoan Animals.—We shall now turn our attention to the simplest group of animals and discover in how far they are similar to the frog. The frog is not the simplest of the amphibians for the salamanders are much more primitive. In a similar manner we shall learn that the protozoan selected for study is not one of the simplest of free living cells but one that is highly specialized. These microscopic animals that are nearly always too small to be seen with the unaided eye can be classified into groups in just the same fashion as the frogs. Eight thousand five hundred different species of proto-

zoans are recognized by specialists of this phylum. There are four main classes that are distinguished by their means of locomotion; by the shape of the body, and by their habitat. Some are wholly parasitic and very destructive to man and animals as in malaria, yellow fever, bubonic plague, etc., but the most of them are harmless and some are even beneficial as they feed on sewage bacteria. Consult appendix for classification.

Habitat.—The animals whose bodies are composed of a single cell are to be found in definite environmental relations to other animals and plants. The mere fact that they are microscopic in size does not imply that the general conditions surrounding them are different from those of other organisms. The habitat of the frog was found to be in definite relation to water, to the seasons and to food.

Paramecium is found in both salt and fresh water and cannot live in any other medium. It is abundant in the temperate fresh-water ponds and streams, especially if the water is stagnant. It is easily kept in aquaria in the laboratory, if supplied with plenty of bacteria such as are present in a hay-infusion. Paramecium is not found in all fresh water. Ordinary drinking-water does not contain it nor is it found in abundance in flowing streams or large lakes. But in water that contains decaying plants and tends to be stagnant, paramecium is usually present. It is not necessarily present even in this ideal habitat, not being found in such conditions unless paramecia have been living there previously, for these microscopic animals follow the same manner of propagation as the frog; namely, there must be living paramecia to give rise to paramecia. When the food conditions are favorable these animals become very numerous, so that a student in a single laboratory period may have several hundred living paramecia for study. These animals are kept in the laboratory throughout the year, and year after year, so that it is evident that they are active throughout the entire year, although very little is known about their winter activities in nature as contrasted with the artificial conditions in the laboratory.

Appearance.—When a drop of water containing paramecia is placed on a microscopic slide they can be seen with the naked eye as grayish rods moving about rapidly. As soon as they are studied under magnification the body is discovered to have a constant shape which is more like a cigar than any other common object. There is a difference in the form of the two ends of the animal, and that end which usually goes foremost is called the front or anterior end. Paramecium can move either forward or backward, but it swims with the

rounded, blunt end pointing in the direction that it is moving except when it becomes necessary to reverse its direction. While it is customary to use the terms anterior for the blunt end and posterior for the pointed end, these two terms do not indicate that there is a clearly defined head or anterior region as in the frog.

The body is broader toward the posterior end, so that the widest part is about two-thirds from the anterior end. In the usual outdoor culture of paramecia there will be found individuals varying in size from 300 micra to as small as 90 micra (a micron is $\frac{1}{1000}$ of a millimeter), which has been shown to be the natural range in size for these single cells of living protoplasm. In such a culture of paramecia it may be possible to distinguish between the larger animals that have the anterior half of the body rather slender and the posterior end markedly pointed, and the smaller forms which are slightly broader in proportion to length and taper less rapidly. When certain additional facts are added to those of size and shape, one can say that two species of paramecia are present.

Structure.—The body of the paramecium is covered with cilia which are slightly longer at the posterior end. On one surface there is a broad groove extending from the anterior end backward obliquely, ending about the middle of the body. As the groove extends posteriorly it deepens. At this place the mouth is located, which opens into a short gullet. For convenience in description the surface upon which this groove occurs is referred to as the oral or ventral surface.

The internal structure may be compared to any typical cell with cytoplasm and nucleus. The cytoplasm of the paramecium is easily recognized as consisting of an outer firm layer with very few coarse granules, known as the ectoplasm; and the inner, coarsely granular layer, the endoplasm. The thin layer of ectoplasm contains numerous rod-like structures, the trichocysts (Fig. 76). The ectoplasm is separated from the surrounding water by a thin cell wall (pellicle). Both the ectoplasm and cell wall are penetrated by the gullet and the anal opening which is located in the posterior part of the body. The living cilia are in connection with the living cytoplasm beneath the cell wall.

Between the ectoplasm and endoplasm are located the two contractile vacuoles, one in the anterior and one in the posterior region. These structures undergo a series of rhythmic changes. There are a number of canals that connect the surrounding region with each vacuole, and as the waste fluid flows through them into the vacuole it gradually becomes distended into a conspicuous vacuole in the part

of the body where it is located. As soon as it is filled a contraction takes place in it and the fluid contents are discharged from the body. The two contractile vacuoles alternate in their action. When one is filling the other is emptying.

Within the thin peripheral layer of ectoplasm is the coarsely granular endoplasm containing a single large, roundish nucleus and one or

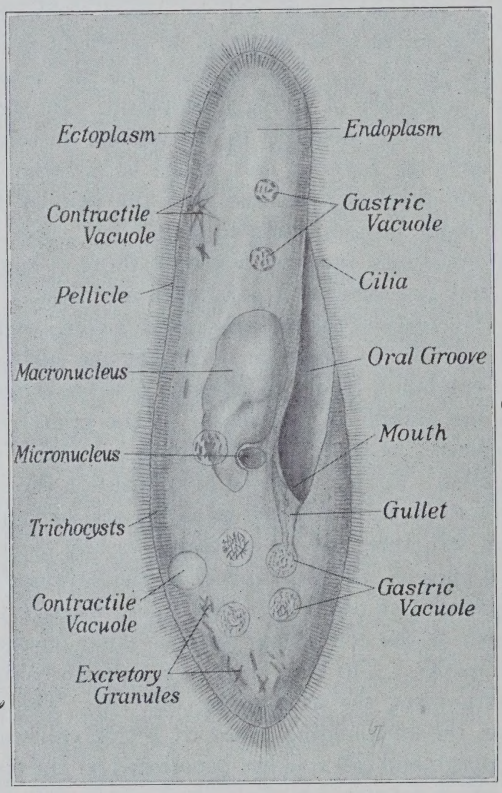


FIG. 76.—*Paramecium caudatum* drawn from living animal by Geo. T. Hargitt.

two micronuclei which are very minute and usually partly concealed, as they lie in a slight hollow in the surface of the macronucleus. The nuclei are located beside the oral groove, near the mouth. There are a varying number of vacuoles scattered in the endoplasm partly filled with food particles surrounded by water. The general term, food vacuoles, may be applied to all such vacuoles. As the animal is

studied under the high power of the microscope it is easy to note that the endoplasm is a fluid through which the food vacuoles may move.

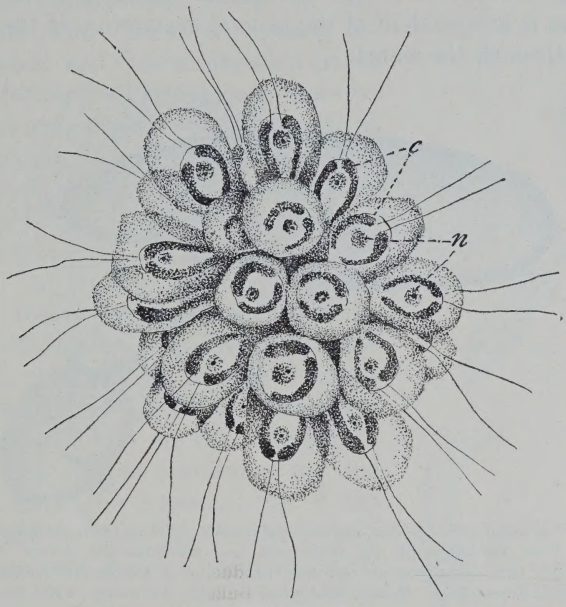


FIG. 77.—*Synura urella*, a colony of phytoflagellates, often a source of disagreeable odors and tastes in drinking-waters. (After Calkins.)

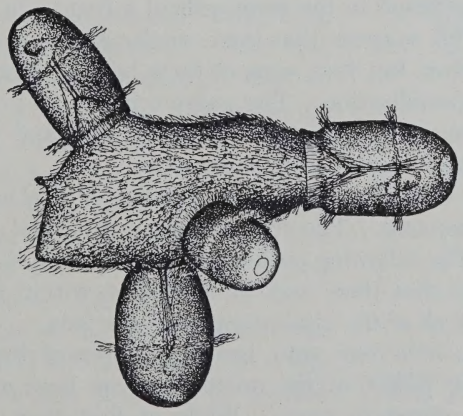


FIG. 78.—A large *paramecium* attacked by four small *didinia*. Under such conditions the *paramecium* is usually torn in pieces and each *didinium* gets a portion. Sometimes, however, one *didinium* gets the entire *paramecium*, forcing the others off during the process of swallowing. (Mast, Biological Bulletin, February, 1909, No. 3, vol. xvi.)

The nuclei and contractile vacuoles retain their position in the cell but the coarse granules and food vacuoles move about with the streaming movement of the endoplasm. This movement of the endoplasm is independent of the general locomotion of the animal as it swims through the water.

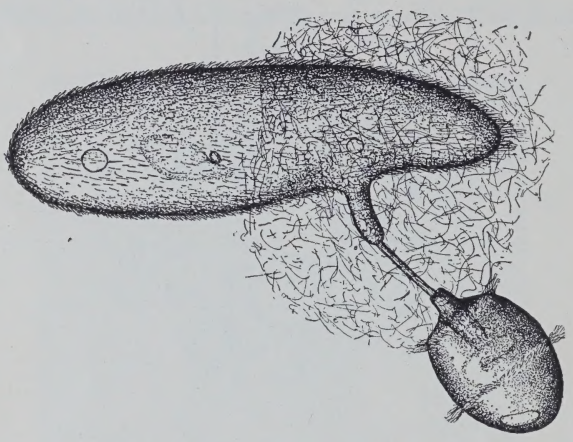


FIG. 79.—A large *paramecium* immediately after having been attacked by a small *didinium*. The discharge of the trichocyst has mechanically forced the *didinium* back, drawing the seizing organ out and producing a marked protuberance on the surface of the *paramecium*. (Mast, Biological Bulletin, February, 1909, No. 3, vol. xvi.)

The single-celled paramecium is thus seen to have more parts than are to be found in the germ cells of a frog or in epithelial cells (Fig. 56). This suggests that these single-celled animals are not all of the same rank, but that some of them have undergone a differentiation and specialization. The paramecium does not represent as simple a form of organization as the amœba and a considerable number of other single-celled animals.

Physiology.—The frog carries on a series of vital activities which are easily compared. The frog utilizes organs and organ systems to do this. The following outline of the vital activities of the paramecium shows that there may be carried on within the protoplasm of a single cell all of the vital processes of the frog.

Locomotion.—No one who has ever observed living paramecia under the low power of the microscope can have any doubt concerning their power to move. While at first their darting movements appear to have no regularity, closer observation reveals that there is a great deal of regularity between what appear at first to be orderless dashings back and forth.

Jennings has given in the following the clearest description found of the general swimming of the paramecium in an unobstructed field: "The paramecium swims by the beating of its cilia. These are usually inclined backward, and their stroke then drives the animal forward. They may at times be directed forward; their stroke then drives the animal backward. The direction of their effective stroke may indeed be varied in many ways. . . . The stroke of the cilia is always somewhat oblique, so that in addition to its forward or backward movement, the paramecium rotates on its long axis. This rotation is over to the left (Fig. 80), both when the animal is swimming forward and when it is swimming backward. The revolution on the long axis is not due to the oblique position of the oral groove, as might be supposed, for if the animal is cut in two, the posterior half, which has no oral groove, continues to revolve.

"The cilia in the oral groove beat more effectively than elsewhere. The result is to turn the anterior end continually away from the oral side, just as happens in a boat that is rowed on one side more strongly than on the other. As a result the animal would swim in circles, turning continually toward the aboral side, but for the fact that it rotates on its long axis. Through the rotation the forward movement and the swerving to one side are combined to produce a spiral course (Fig. 80)."

The movement of the paramecium in an unobstructed field is thus seen to be a regular spiral, which may be said to be as characteristic as is hopping for the frog. But when the paramecium meets an obstacle, another paramecium or food its movements are equally characteristic, and a specific

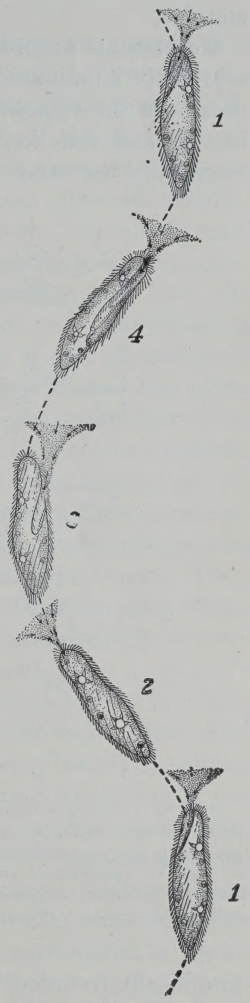


FIG. 80.—Spiral path of a *paramecium*. The figures *1*, *2*, *3*, *4*, etc., show the successive position occupied. The dotted areas with small arrows show the current of water drawn from in front. (From Jennings.)

description can be given in each instance. In a more intensive study of the paramecium these various forms of activity are readily distinguished. Compare these movements with those in amœba.

Movement in Amœba.—When an amœba is moving about and enters a brightly illuminated area, in nearly all instances it stops. "The details in the response which resulted in the change in direction of motion and thus kept the organism out of the intense light were essentially the same in all of the specimens observed. They are

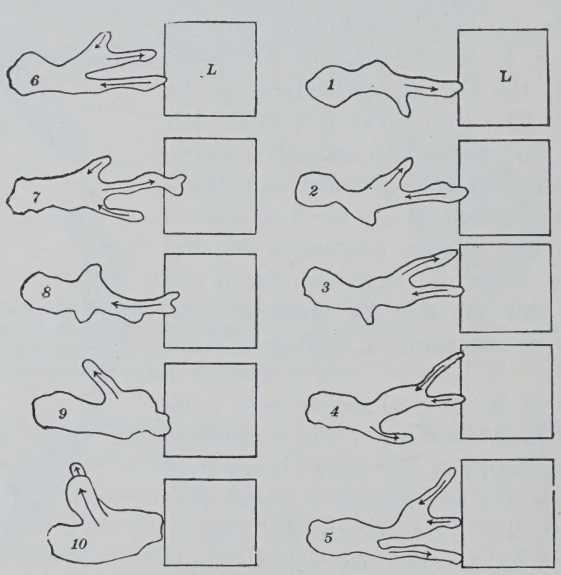


FIG. 81.—Sketches representing the reactions of an amœba proceeding toward an intense area of light, the rays of which were perpendicular to the slide. *L*, field of light formed by focussing a limited section of a Welsbach mantle on the slide. 1 to 10, successive positions of an ameba a little less than one-half minute apart. Arrows indicate direction of streaming pseudopods. Compare this method of locomotion with paramecium. (From Mast, Jour. Exper. Zoöl.)

graphically recorded for a single individual in Fig. 81. By referring to this figure it will be seen that after one pseudopod came in contact with the illumination and was stopped, the amœba did not at once proceed in the opposite direction so as to avoid the light, but sent out other pseudopods at only a slight angle with the first, apparently trying to get around the obstacle in this way. The character of the response did not change after the first pseudopod came in contact with the light, nor did it change after the second and third came in

contact with it. But after the fourth became exposed the direction of motion was nearly reversed. This indicates that the reaction was modified, that the response to a given stimulus depends upon preceding experience." (Mast.)

Regulation of Reactions.—When we ask how these responses in protozoa are regulated, we are proposing to examine a very fundamental biological problem. There is one group of thinkers which assumes that the physical and chemical factors of the environment hold the secret; while another group asserts that these reactions are an expression of the organization of protoplasm. Jennings emphasizes this second conception in his analysis of the internal factors. He performed experiments that showed conclusively to him, at least, that activity may change without external causes and that the behavior of an organism at any moment depends on its physiological state at that moment, and that the resolution of one physiological state into another becomes easier and more rapid after it has taken place a number of times. A wider application of this interpretation has been made by C. W. Hargitt in his study of Tubicolous Annelids, in which he concludes that if we may regard these organisms, not as mere machines, but as individual beings endowed with an organization, both physical and physiological, then these variable phenomena of behavior are only such as conform to natural expectation. They form an integral part of that living world, from monad to man, whose correlated behavior, in its ultimate essence, differs relatively according to the complexity of the organism concerned.

Food.—Large quantities of bacteria are present in water in which paramecia are abundant, since these minute plants are their chief food. The activities of the paramecium in feeding consist in placing the body against a mass of bacteria and stopping the action of the cilia on the body, while those on the oral groove produce a strong current of water directed toward the mouth. The bacteria are thus carried to the mouth and swallowed. As the masses of bacteria pass into the endoplasm a small amount of water is also taken in. The result is the production of a distinct structure, surrounded by endoplasm called the food or gastric vacuole.

The number of food vacuoles depends upon the abundance of bacteria available. As the vacuoles accumulate in the endoplasm they can be seen to pass posteriorly and then gradually move toward the anterior end, finally, however after several hours, being extruded from the body through the anal opening.

Digestion.—The gastric vacuoles in the endoplasm of the paramecium may be compared to the stomach of the frog. Neither

the insects which are in the stomach of the frog nor the bacteria in the gastric vacuoles of the paramecium can be built up into living protoplasm until they have been digested. There are no digestive glands or special structures, so far as one can observe, whose main function it is to transform these bacteria, which are composed of proteins, carbohydrates and possibly fats, into diffusible products. It has been demonstrated that there is a mineral acid in the gastric vacuoles which kills the bacteria, after which the bacteria are seen to swell and then pass into solution. This is probably similar to protein digestion in the higher animals. Inasmuch as there are definite digestive ferments or enzymes that transform the food in all of the higher animals, it is assumed that one or more digestive enzymes are produced by the protoplasm of the paramecium because proteins, carbohydrates and fats are absorbed from the gastric vacuoles. The paramecium is thus able to digest and assimilate food in a manner similar to the many-celled animal.

Excretion.—It is believed that the contractile vacuoles collect and discharge waste products to the outside of the body of the paramecium. There are also some specific granules which are regarded as excretory although their exact function is undetermined. As the excretory waste flows into the contractile vacuoles and then is in turn discharged from the body a certain amount of movement is produced in the endoplasm which probably helps in circulation.

Respiration.—In addition to taking in food and giving off waste, the paramecium must have oxygen. This it is able to take from the water. There is no definite part of the body of the paramecium concerned in taking oxygen that is comparable with the lungs of the frog.

Metabolism.—The manner in which the paramecium uses food, the evidence in favor of excretion and the utilization of oxygen warrant the use of the term metabolism in the same sense that it was used in describing similar activities in the frog.

Neuromotor Apparatus.—Rees[1] has recently demonstrated that paramecium like at least two other species of protozoa has a highly specialized system of fibers in the ectoplasm. These branching fibers are connected to the basal granules of the cilia and to the trichocysts. The fibers converge from the periphery to the neuromotor center in the region of the gullet. This fibrillar apparatus is interpreted by Rees as a conductile system and plays, therefore, an important part in coördination.

These special structures in paramecium and those found in the

[1] Rees, C. W.: The Neuromotor Apparatus of Paramecium, American Naturalist, 1921, **55**, 464

stalk of vorticella indicate that specialized portions of the cell for contraction and conduction were developed early in the life of animals, and it is easy to understand how these two important functions of protoplasm came to dominate certain cells until their other functions were secondary. In the formation of the neuromotor apparatus, contractile vacuoles, and a gullet, paramecium suggests the beginning of that differentiation which culminates in tissues in the metazoa.

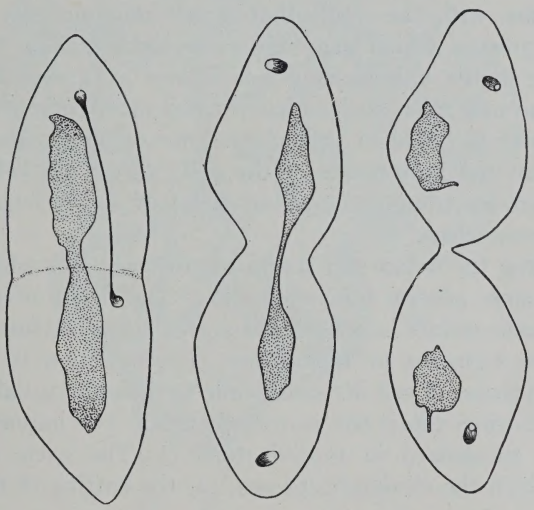


FIG. 82.—*Paramecium caudatum*, showing fission drawn from author's preparations. Notice the irregularity in the outline of the macronucleus which appears to be a normal feature.

Reproduction.—That this elementary vital process is present in the paramecium is the common observation of students every year. Either cells are seen dividing or swimming about in pairs. The dividing cells are reproducing by a process known as *fission*, which is the usual method (Fig. 82). The micronucleus divides first, then the cell divides through the middle of the macronucleus. A new mouth has to form on the posterior half and an extra contractile vacuole in each half. Woodruff has carried on a continuous series of observations upon the species of the paramecium known as aurelia, and this animal has been recorded as dividing for more than six thousand times by the process of fission. Each time that a paramecium divides there are no parents, but the individual has become merged into two offspring. In a species like aurelia it would seem as if one might almost say that it is immortal.

Conjugation.—In both species of paramecia that have been studied there are certain periods when two animals unite temporarily, during which there is a definite exchange of a fraction of the micronuclei. After each paramecium has thus received this small amount of nuclear substance the animals separate. Preceding this exchange of micronuclear material a complicated series of changes has taken place in the micronucleus of each. There appears to be a definite fusion between the micronucleus introduced into the paramecium and the portion that remains, with the result that a new micronucleus is formed. After this process, which some writers regard as similar to fertilization in the higher animals, the cell divides by fission, but in this instance the new micronucleus has divided into four nuclei and the macronucleus has broken up into fragments which are gradually absorbed by the protoplasm of the cell. After the cell has thus divided there are two micronuclei in each half, one of which becomes a new macronucleus.

In the frog the ovum and sperm are distinct cells which may be given the more general term of *gamete.* The fusion of a male and female gamete results in a fertilized egg or *zygote.* After this fusion the embryo segments or reproduces. Reproduction is in the last analysis a process of cell division; while fertilization usually precedes such cell divisions this is not universally true. Two important phases should be recognized in reproduction: (1) The cycle of changes through which the chromatin passes; (2) the cutting of the cell into two parts.

Sexual reproduction in higher animals and plants has in common the features just summarized. To what extent can the origin of this process be derived from the protozoa? The answer to this problem cannot be final until the present studies on reproduction in protozoa are completed. Woodruff has carried paramecium aurelia through 8400 generations of asexual reproduction without conjugation. But this should not obscure the important fact that conjugation is a common phenomenon in protozoan life where in such forms as vorticella there is an actual fusion of two cells of unequal size. In such a protozoan one has what is essentially a male and female gamete fusing into a zygote.

After conjugation in some forms there is a stimulating of all vital processes, and it seems permissible to recognize in conjugation a very simple form of fertilization.

Organic Movement.—In order that the paramecium may be able to carry on all of these vital activities, it must have been able to coordinate its movements. In an analysis of these movements it is

customary to separate them into the following which are regarded as elementary properties of protoplasm: *Irritability*, which enables the protoplasm to respond to a stimulus; *conductivity*, by means of which the effect of the external stimulus is communicated to all parts of the cell; as these two properties respond the protoplasm con-

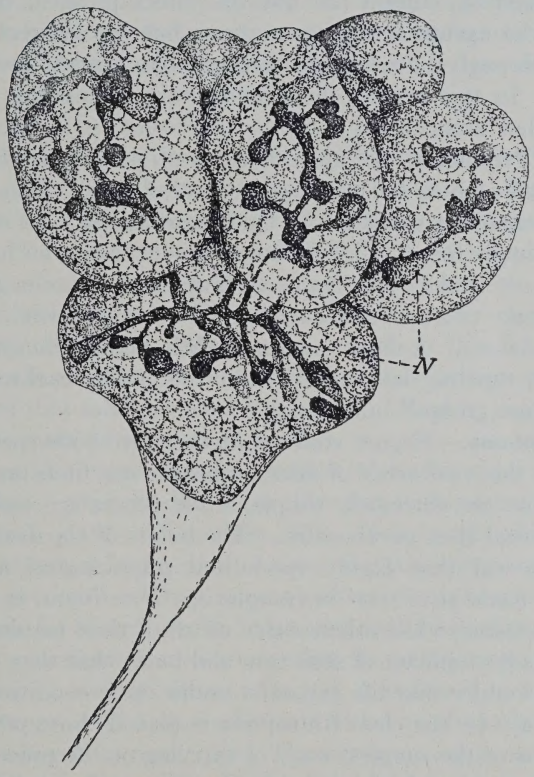


FIG. 83.—*Ephelota bütschliana*, a budding individual with five daughter buds. *N*, macronucleus, which forms a branching organ connected throughout. Reproduction by budding is a form of fission. Notice the branching form of the macronucleus in each bud. (After Calkins.)

tracts, which is the third property, *contractility*. These three are bound up in such a way that the animal is able to move in a definite direction; in other words, to correlate or coördinate its response to a definite stimulus. These are the same reactions that the frog is able to carry on by means of the nervous system and muscles. Jennings, page 261, states several important facts in regard to reaction of

single-celled animals, two of which are quoted: "First, we find that in organisms consisting of but a single cell, and having no nervous system, the behavior is regulated by all the different classes of conditions which regulate the behavior of higher animals. In other words, unicellular organisms react to all classes of stimuli to which higher animals react. Secondly, the reactions produced in unicellular organisms by stimuli are not the direct physical or chemical effects of the agents acting upon them, but are indirect reactions, produced through the release of certain forces already present in the organism. In this respect the reactions are comparable with those of the higher animals."

Kinds of Paramecia.—In most cultures of paramecia there will be found animals which fall into two general classes: "(1) Caudatum group (*Paramecium caudatum*). One micronucleus" (as seen in Fig. 70). "Animals larger, slightly more slender, posterior half of body tapering more rapidly and regularly than in the aurelia group. (2) Aurelia group (*Paramecium aurelia*). Two micronuclei, unlike the one in caudatum. Animal smaller, slightly broader in proportion to length, and tapering less rapidly from the middle backward than in the caudatum group." (Jennings.)

Other Protozoa.—Hegner states that there are 8500 species of protozoa. In this vast array of microscopic life one finds many adaptations. Some are extremely simple, while others are more complex and specialized than paramecium. The habits of the disease-causing protozoa reveal that highly specialized physiological adjustments have been made that rival in complexity those found in any of the higher organisms; while others carry on all of their manifestations of life with such simplicity of structure and habit that they continue to excite our wonder that life can exist under these conditions.

Rhizopoda.—In the class Rhizopoda is placed those protozoa that exhibit some of the simplest ways of carrying on life processes. Here we find the amœba which has been more frequently studied than any other member of the phylum protozoa.

It is very common, although not abundant, in fresh and salt water. There is no limiting cuticle or cell wall so that the ectosarc is in direct contact with the water. The streaming of the ectosarc and endosarc results in the formation of irregular processes that serve the amœba as "organs" of locomotion and as "feelers." These out-streamings are called *pseudopodia*, because they are neither constant nor permanent, being continually formed and withdrawn when the amœba is active. There are no specialized organs of locomotion like the cilia on the paramecium.

Food vacuoles, a contractile vacuole and the nucleus are the structures, together with the cytoplasm, through which the vital activities are carried on. This very simple bit of streaming, naked protoplasm maintains its identity from generation to generation and has characteristics that permit one to classify it as a definite species.

The source of vital energy in the complex frog, the specialized paramecium, and this very simple bit of protoplasm is the same, organic food. None of these animals can manufacture food-energy from the raw elements in Nature. Each is, therefore, dependent for its food supply on other forms of life.

Flagellata.—The unicellular animals placed in this class reveal some interesting and instructive biological relations. The flagellata are characterized by having one or two whip-like cilia projecting from the cell. This specialized cilium is known as a flagellum (plural flagella). The presence of a flagellum is the most conspicuous structural feature in recognizing these minute animals.

Euglena viridis is a well-known member of the class flagellata. There is a rudimentary gullet but no mouth in this cell nor is food engulfed as in amœba. Recent critical studies indicate that there is no evidence that solid particles of food are utilized by euglena. What then is the source of its vital energy?

In the endosarc are found a number of bodies that are green in color. These green bodies have the same characteristics as the *chloroplasts* in plants. (See page 131). If we study the activity of euglena through a long period of time, we gain some insight into its metabolic processes. When large numbers of euglena are kept in a mass culture for several weeks, it is noted that while there are numerous starch granules in the endosarc, that the animals are not dividing. If the water of such a culture is tested, it is found to be lacking in organic nitrogen. If amino-acids are added to the culture medium, the euglena begins to reproduce. The nitrogen compound is absorbed directly through the cell wall, thus enabling the animal to manufacture protein substance, which, in turn, is necessary for growth. Euglena kept in the dark gradually cease dividing and the green color disappears. When such animals are placed in a 5 per cent dextrose and $\frac{1}{100}$ per cent amino-acid solution, they begin to grow although still in the dark.

This experiment indicates that the carbohydrate and protein metabolism must be balanced and that this can be regulated artificially.

Such an organism has thus the characteristics of both plants and animals. It is really neither. By some writers it is described as

autotrophic (self-feeding) because it can utilize the raw elements in Nature; while the amœba, paramecium and frog are mixed, dependent feeders and so described as *heterotrophic.* In our effort to gain further information about the metabolism of food compounds and the manner in which they are made available as food-energy, we shall examine the conditions of some of the simple plants.

Protozoön Animals.—The study of the paramecium serves to show how an animal composed of only a single cell may carry on all of the necessary vital activities of the more complex animal such as the frog. The paramecium is an organism without any of the morphological structures which go to make up the bodies of higher animals. The whole life is lived within the limits of a single cell. In view of the fact that a single protozoön lives but a few hours and then divides, merging its individuality into two or more offspring, one cannot use the term life cycle as it was used in the frog. But the protoplasm of which an individual is composed goes on generation after generation, and to these changes the term life cycle can be given.

In addition to the class infusoria of which paramecium is an example, there are the following with a few of the disease-causing species indicated.

- Protozoa
  - Rhizopoda
    - *Amœba* . .
      - *Amœba dysenteriæ*
      - *Amœba coli*
      - *Amœba meleagridis*
      - *Amœba buccalis*
  - Flagellata
    - *Spirochæta* .
      - *Spirochæta obermeieri*
      - *Spirochæta duttoni*
      - *Spirochæta vincenti*
      - *Spirochæta pallidula*
      - *Spirochæta theileri*
      - *Spirochæta gallinarum*
    - *Trypanosoma*
      - *Trypanosoma gambiense*
      - *Trypanosoma cruzi*
      - *Trypanosoma bruzei*
      - *Trypanosoma evansi*
      - *Trypanosoma equinum*
      - *Trypanosoma dimorphon*
      - *Trypanosoma lewisi*
      - *Trypanosoma equiperdum*
    - Trypanoplasma
    - Cercomonas
    - Monas, etc.
  - Sporozoa
    - Hæmosporidia
      - Plasmodium
        - *Plasmodium vivax*
        - *Plasmodium malaria*
        - *Plasmodium falciparum*
      - Proteosoma
      - Hæmoproteus
      - Hepatozoön, etc.
  - Infusoria

Summary of What Has Been Learned About Life in this Study of Paramecium.—1. The same method of making observations, grouping the facts and trying to explain their significance has been employed as in the study of the highly specialized organism *Rana pipiens.*

2. Paramecium is a unicellular organism that has become specialized in its method of locomotion and neuromotor apparatus, its two nuclei, one being mainly metabolic and the other reproductive, and in its means of defense, the trichocysts. In its remaining features it is a very simple organism.

3. Paramecium has specific morphological characters that enable one to give it a definite place in the phylum protozoa and to further characterize it as a distinct species.

4. Paramecium exhibits all of the manifestations of life so evident in the frog, requiring oxygen and food-energy, giving off wastes, responding to changes in its environment and reproduction. All of these physiological processes are found within the limits of a single cell. These manifestations of vitality are adequate to the life of a protozoan. They appear to be identical with similar processes in the frog. *Life, then, can carry on all of its normal phenomena without cell differentiation into tissues and organs.*

5. The limits of the microscope in magnification and the limits of vision in the human eye prevent us at present from really seeing just how all of these physiological changes take place. We shall have to wait for new inventions improving the microscope or different methods of studying the protoplasmic changes before we can hope to learn more.

Biology of Cells.—The study of paramecium has served as an introduction to the biology of unicellular organisms. The next two chapters illustrate other phases of this same problem. The three combine to furnish the modern point of view in biology and serve as a background for the remainder of the book.

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CHAPTER IX.

PLEUROCOCCUS—A PLANT CONSISTING OF A SINGLE CELL.

Habitat.—Everyone has noticed the greenish layer which occurs so commonly on tree trunks, moist rocks, wooden fences and similar objects. This layer is dull green in color and powdery in texture when dry, but when moistened by rain the color becomes brighter and the layer becomes somewhat slimy to the touch. Under the microscope this green material is found to be composed of thousands of very small cells or groups of cells of the plant pleurococcus. This plant is truly cosmopolitan in distribution, being found in the habitats mentioned in all parts of the world under the most diverse conditions of temperature and moisture. In north temperate regions it is usually found on the north face of vertical objects, *i. e.*, the shaded and moister side.

Morphology.—A single plant of pleurococcus consists of a spherical cell of variable size, ranging from 5 to 15 micra in diameter. Such separate plants are readily found; but more commonly they occur united into groups or colonies of two to a dozen or more cells. In such colonies the individual cells are not spherical but assume various irregular shapes because of the pressure of adjacent cells.

Each plant consists of a protoplast surrounded by a cell wall. The cell wall is thin and transparent and somewhat gelatinous on the outer surface; chemical tests show that it is composed of cellulose. It is non-living, therefore not a part of the protoplast; instead it is formed or secreted by the protoplast. The formation of such non-living cellulose walls is characteristic of plant protoplasts and occurs but rarely in animals.[1]

The protoplast consists of a nucleus and one or sometimes two chloroplasts embedded in grayish or colorless cytoplasm. The nucleus lies near the center of the cell, is spherical in shape and measures from 2 to 4 micra in diameter; it contains one or more nucleoli and shows a netted or reticulate structure which includes the chromatin. The chloroplast is bowl- or trough-shaped with the convex surface outward; it lies near the surface of the protoplast but is

[1] In this chapter certain terms of current botanical usage are applied to both plants and animals; this seems desirable in order to facilitate comparison of the structures and processes of the two groups of organisms. Loren C. Petry.

wholly surrounded by cytoplasm. In an isolated plant of spherical shape it may almost entirely surround the nucleus; but in cells which form part of a colony it is smaller and assumes a position in the curved part of the cell, *i. e.*, in the part most immediately exposed

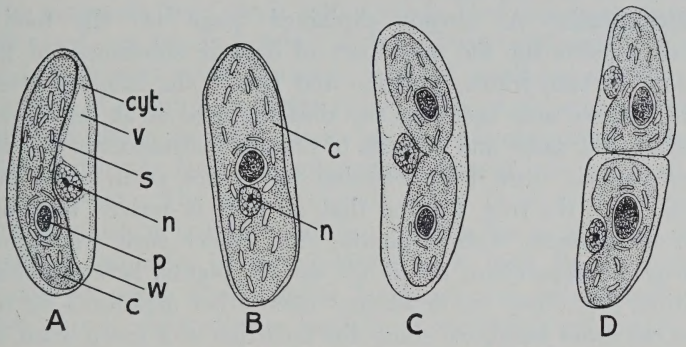

FIG. 84.—*Mesotænium*, a unicellular green plant. *w*, cell wall; *cyt.*, cytoplasm; *v*, vacuole; *n*, nucleus; *c*, chloroplast; *p*, pyrenoid; *s*, starch grain. The chloroplast is a thick, curved plate; side and top views of it are shown in *A* and *B*. *C*, *D*, stages in reproduction by cell division. × 1070.

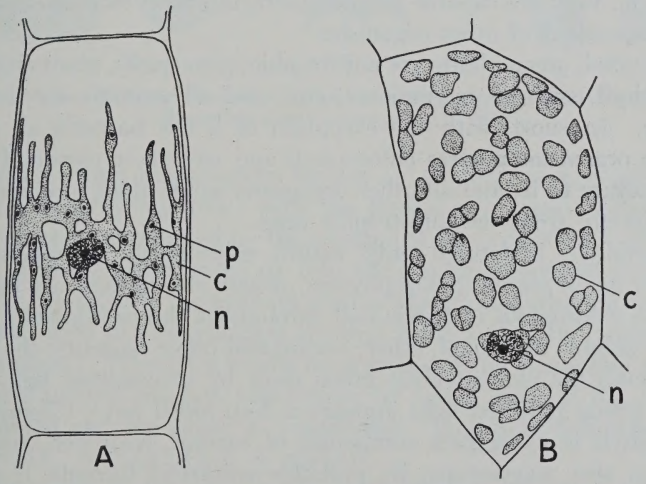

FIG. 85.—Surface views of plant cells, showing different forms of chloroplast. *c*, chloroplast; *p*, pyrenoid; *n*, nucleus. *A*, cell of *Draparnaldia*, with single elaborate chloroplast; *B*, cell of fern prothallium with many simple chloroplasts. × 680.

to light. The chloroplast of a living plant of pleurococcus is bright green in color, due to the presence within it of the pigment chlorophyll. If the cells are placed in alcohol the chlorophyll is dissolved out; the chloroplast is seen to be unchanged except in color, which

is now grayish, while the chlorophyll, if present in sufficient quantity, colors the alcohol a characteristic green. It is important to note this distinction between the chloroplast, which is a living organ of the protoplast, and the chlorophyll, which is a green pigment contained in the chloroplast.

Photosynthesis.—As already explained (page 44) the food of animals consists for the most part of organic substances of three groups: carbohydrates, proteins and fats. The same is true of plants, and we may therefore say that the food of all organisms is essentially the same and consists of organic substances of the three groups named. But if we examine the source of the food of an animal, *e. g.*, the frog, we find that all of it is derived from other organisms—insects, worms, plants, etc. Hence such organisms as the frog are dependent, or, as we say for plants, heterotrophic in nutrition, *i. e.*, they are dependent upon other organisms for food. If, on the other hand, we study the nutrition of a green plant such as the pleurococcus it becomes plain that its food is not brought in from outside the organism but is manufactured *in situ* from inorganic materials. Such organisms are independent or autotrophic in nutrition, *i. e.*, they are capable of manufacturing their own food and so are independent of other organisms.

In general, green plants are autotrophic; conversely, plants lacking chlorophyll, such as mushrooms, etc., and all animals are heterotrophic. In short, with the exception of a few bacteria all autotrophic organisms possess chlorophyll and owe their power of food manufacture to it; and all other organisms secure their food directly or indirectly from the autotrophic ones.

Chlorophyll is formed only within chloroplasts except in the simplest green plants (Schizophyceæ), where chloroplasts are lacking and the chlorophyll is distributed throughout the protoplast. It is readily soluble in alcohol, ether, benzol and other reagents; the solution shows the characteristic green color by transmitted light, but under strong reflected light appears a deep blood red. Chemically, chlorophyll is a complex compound of carbon, hydrogen, oxygen, nitrogen and magnesium; its probable empirical formula is given by one investigator as $C_{54}H_{72}O_6N_4Mg$. While not a constituent of chlorophyll, iron is always present in the chloroplast and seems to be essential to chlorophyll formation. Either in solution or in the living plant chlorophyll absorbs part of the light which falls upon it. As shown by the spectroscope, this absorbed light consists of a series of rays of various wave-lengths; but for the most part the absorption is of the red-orange and blue-violet rays while the yellow-green

rays are transmitted unhindered. The energy of the light thus absorbed in the chloroplasts is available for the work of the plant and is used to bring about the manufacture of food. Obviously, therefore, the process can go on only in the presence of the light necessary to afford the energy, *i. e.*, in nature, in the daytime.

The materials from which carbohydrate food is manufactured by green plants are two in number, carbon dioxide and water. Carbon dioxide is present in the atmosphere in the small but constant concentration of about 4 parts per 10,000 parts of air, and is therefore readily available to such plants as the pleurococcus. Water is absorbed directly from the substratum through the cell wall into the protoplast. The carbon dioxide taken in is dissolved in the water in which it is readily soluble. While the exact steps in the process of formation of carbohydrate foods from these substances are not yet clear the essential facts are well established. The carbon dioxide and water are partially or completely reduced to their

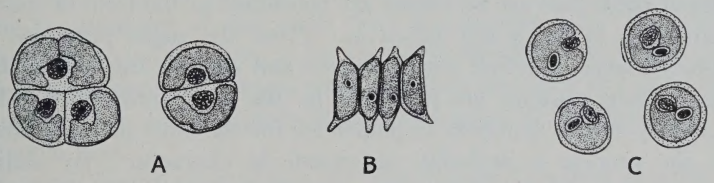

FIG. 86.—Colonies of various unicellular green plants. *A, pleurococcus, B, scenedesmus; C, tetraspora.* × 800.

elements, which immediately recombine to form a monosaccharid sugar (probably dextrose) with the freeing of oxygen. These two processes are represented by the reaction $6CO_2 + 6H_2O = C_6H_{12}O_6 + 6O_2$. The oxygen is given off into the atmosphere through the cell wall. The sugar is the primary food of the plant, being the principal material used in the synthesis of other foods and in the processes of metabolism. When it is produced in excess of the immediate requirements a further reaction takes place by which some of the water is eliminated and the sugar is "condensed" in starch; this reaction is $n(C_6H_{12}O_6) = (C_6H_{10}O_5)n + n(H_2O)$.

This starch is deposited in the chloroplast as granules or "starch grains" and forms a reserve food supply for the cell; in green plants kept in darkness the starch grains soon disappear and reappear only after the plant has again been in the light for a considerable period of time. In some plants, *e. g.*, vaucheria, the excess food is stored in the form of a fat or oil, but it is probable that here also the first food formed is a sugar.

This process by which carbohydrates are manufactured in green plants is called photosynthesis; its essential features are summarized as follows: The materials used are carbon dioxide and water; the energy is obtained from sunlight absorbed by chlorophyll; the chloroplast by the use of this energy brings about a chemical synthesis of the materials, resulting in the freeing of oxygen and the production of a sugar, some of which is usually transformed into starch and stored in that form.

Other Materials and Syntheses.—In the life processes of green plants certain mineral substances are necessary in addition to the carbohydrates produced by photosynthesis. As mentioned above, magnesium is a constituent of chlorophyll, and iron is always present in the chloroplast; these elements are therefore essential to the metabolism of green plants. In addition to these, nitrogen, potassium, phosphorus, calcium and sulphur are required by most plants. In the case of simple forms like the pleurococcus the very minute quantities of these that are necessary are contained in the form of soluble compounds in the water taken in. From the sugar produced by photosynthesis, together with nitrogen and sulphur taken in in this way, various proteins are produced by the living protoplast. The details of protein synthesis in plants are for the most part unknown, but the process is probably enzymatic in character. By similar processes fats are also formed from carbohydrates. This occurs in the pleurococcus especially at periods when the plants have become very dry and are in an inactive or resting condition; at such times little or no starch is formed while fats are present in quantity.

Metabolism.—As already defined (page 61), metabolism includes all the processes which have to do with the use of food by the organism. These processes in simple plants, such as the pleurococcus, differ in no essential features from the corresponding processes in the paramecium and other simple animals. The foods produced by the processes just described are assimilated by the protoplast, resulting in the formation of new protoplasm and consequent growth of the cell. Similarly, the process of respiration takes place continually in the pleurococcus as in all other organisms, resulting in the formation of carbon dioxide and water and the releasing of the energy necessary for all the life processes of the protoplast, except photosynthesis (page 58).

Reproduction.—As a result of the assimilation of food, growth of all parts of the cell results. The cell wall is elastic and is stretched by the increased volume of the protoplast; its normal thickness is maintained by the deposition upon its inner surface of new layers

of cellulose by the protoplast. The chloroplast also enlarges and ultimately divides into two. The nucleus enlarges for a time, then divides mitotically (page 101). A cell wall is formed between the two daughter nuclei, dividing the original cell into two similar cells, each containing cytoplasm, a nucleus and a chloroplast. The newly formed cells may separate at once or they may adhere for a time, forming groups or colonies of cells. This simple division of the original plant to form two plants is the only form of reproduction known to occur in the pleurococcus.

Importance of Photosynthesis.—In our studies thus far it has been shown that the simple and the complex animal and the simple plant require energy in the form of food to maintain their vital processes. For these specific organisms may be substituted the expression all organisms require energy in the form of food to maintain their vital processes. In the final analysis then all animals and all but a very few colorless plants (Chapter X) ultimately depend on the synthetic activity of the chlorophyll in the plastids. The annual money value to mankind of this food thus manufactured in the United States is in round numbers at least $15,000,000,000. All of this vast sum is dependent on natural processes that man has not been able to imitate since the first plant developed a mass of chlorophyll in the unknown past.

A recent investigator points out that Nature's method of utilizing solar energy in this manufacturing of food in green plants is exceedingly inefficient and wasteful. This startling conclusion is based on the computations of Dr. Spoehr, who concludes that the green plant life utilizes not more than 1 per cent of the radiant energy that falls on it from the sun.

What solar energy is caught and held is stored up, so to speak, in the form of starchy and woody stuffs from which the energy can be released in the form of heat when the stuff is burned. But if it is food we want from the plant instead of fuel its yield is still more limited, for we human beings with our restricted digestive apparatus cannot get nutriment out of the woody fiber as we can out of the sugar and starch. How much then of the solar energy that falls, say, on a wheat field can we get out in the form of the edible grain to furnish us with muscular energy? An acre of ground receives in six hours of sunshine as much heat energy as would be produced by the combustion of 16.4 tons of coal. In a growing season of ninety days at this rate per day the total income of energy would amount to 1476 tons of coal. Now what is the yield, likewise calculated in terms of heat units derivable from coal? Taking the very large crop

of 50 bushels of wheat per acre and calling it all starch, we get an energy equivalent of less than $\frac{2}{3}$ of 1 ton of coal.

It is conceded by mining and geological experts that eventually civilization will exhaust the coal and oil stored by Nature in the past. Mankind will then be compelled to turn to solar energy for his supplies of heat, fuel and food. When these two new requirements are added to our needs for food, and fuel it is evident that the study of the relation of solar energy to the formation of food compounds is one of the most important scientific problems facing mankind. Some of the men working on this problem believe that the complete understanding of the action of light on green plants determines the destiny of civilization. A full understanding of this problem will throw an important searchlight upon the still unsolved origin of life. For in such a solution would be found the answer to the question whether animals or plants were the first form of life to appear.

Other Unicellular Green Plants.—Microscopic examination of water from ponds, streams or laboratory aquaria will usually show some forms of unicellular green plants. Especially common in aquarium jars is Scenedesmus, with spindle-shaped cells grouped in colonies of four. Pond waters usually contain numerous desmids (Closterium, Cosmarium, etc.), which are characterized by curiously shaped bilaterally symmetrical cells with very complex chloroplasts. Diatoms, with cell walls of silica instead of cellulose, and containing a brown pigment in addition to chlorophyll, are abundant in all waters and moist places.

Summary.—1. The method of study found to be most successful in learning the fundamental principles of animal life apply equally well to a microscopical plant.

2. Pleurococcus exhibits the several manifestations of life as paramecium except movement.

3. This green cell, like all green plant cells, can utilize the raw or very simple inorganic compounds by transforming them into food products.

4. Photosynthesis is a distinctive feature of all green plants and gives to them the distinction of being constructive organisms; while animals are destructive in that they require organic food to maintain their life.

5. This contrast between paramecium and pleurococcus establishes the difference between unicellular animal life and unicellular plant life and the same generalization is true for all of the higher organisms.

CHAPTER X.

BIOLOGY OF BACTERIA AND YEAST—THE SIMPLEST LIVING ORGANISMS.

Organized Ferments.—This chapter is limited to a general survey of the more important of the so-called organized ferments. This expression was applied at first to such forms of cell life as have the ferment associated with the life of the cell, and in one sense the term organized ferments may be retained, since in Nature these intracellular[1] enzymes are found acting through the living protoplasm that produces them. They are not poured out as is the saliva or the pepsin, which may be described as extracellular enzymes. It was believed for many years that these ferments could not be separated from the protoplasm which produced them and that their ferment action ceased with the death of the protoplasm. Büchner demonstrated that yeast could be ground with infusorial earth and a juice extracted which had the power to cause alcoholic fermentation. The yeast plant may be killed by alcohol, ether or acetone and still retain its power to cause fermentation. In a similar manner the bacteria which cause lactic acid in milk can be killed, so that they do not grow or divide, and yet they can form lactic acid. These experiments are difficult to perform, but are valuable as showing that the enzymes are to be classed as similar to those found in the higher animals and plants.

Yeast.—The word yeast is a general name for a half-dozen or more distinct species of plants found growing wild and cultivated. Because yeasts feed upon sugar the term saccharomycetes is given them. These plants are necessary in bread-making and in the manufacture of liquors. If yeast is to grow and thrive the temperature may range from 9° to 60° C. When dried it can endure a higher temperature, but it requires a definite environment if it is to live.

Morphology of Yeast.—If a small amount of compressed yeast is mixed with water and then examined with the microscope a large

[1] Vernon: Intracellular Enzymes, 1908.

number of oval and egg-shaped bodies are seen. The majority are either unicellular or have small buds attached. Sometimes a short chain of buds is noted. There is a definite cell wall composed of "yeast cellulose." The living protoplasm is granular and usually contains a number of vacuoles filled with sap. The beginning student frequently mistakes the sap vacuoles for the nucleus. Many minute glistening dots can be made out which are probably fat. No chlorophyll or starch is found in the protoplasm. The nucleus is a coarsely granular body and can be differentiated by the use of proper stains.

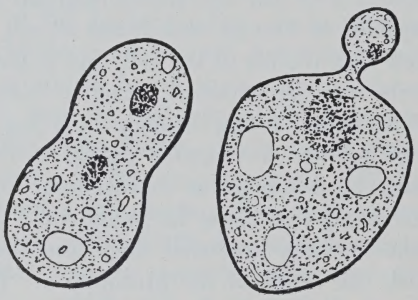

FIG. 87.—Yeast cell showing nucleus. Work out the method of budding in the laboratory.

Reproduction of Yeast.—The usual process of reproduction is easily seen in any study of yeast in water. The method is similar to fission in protozoa, except that there is a large parent mass and a small offspring. The nucleus divides by amitosis and the bud remains attached for some time. Occasionally yeast exhibits the formation of spores by a process which results in dividing the protoplasm of the cell into two, three or four distinct masses. When the old cell wall breaks down under proper environmental conditions each spore is capable of starting a new series of yeast plants.

Food of Yeast.—Pasteur devised a solution which contains no organic nitrogenous matter; the nitrogen is in a more complex compound than the nitrates, which are utilized by green plants (page 132).

Water, H_2O	83.76	per cent.
Cane-sugar, $C_{12}H_{22}O_{11}$	15.00	"
Ammonium tartrate $(NH_4)_2C_4H_4O_6$	1.00	"
Potassium phosphate, K_3PO_4	0.20	"
Calcium phosphate, $Ca_3(PO_4)_2$	0.02	"
Magnesium sulphate, $MgSO_4$	0.02	"
	100.00	"

The yeast is able to grow in this fluid and to make more protoplasm; it must therefore have been able to utilize inorganic material as the whole source of its food energy. This is a physiological property that is probably lacking in the unicellular animals, although some recent researches assign a rather higher synthetic power to animals. The green plant cells are able to utilize simpler nitrogen compounds than is the yeast, so that the yeast occupies an intermediate position between animal and green plant cells in its ability to manufacture its own food out of the raw elements. It can use nitrogen in the higher forms of proteins, and in this sense approaches more closely to the animal cell. Free oxygen is as necessary to yeast as to other forms of living matter. The anaërobic bacteria such as the intestinal bacilli and many others are exceptions to this general statement.

Metabolism.—The yeast plant is able to build up its own food from the mineral substances furnished in Pasteur's solution and to utilize them in the making of more yeast protoplasm. The series of changes through which foods must pass in becoming living protoplasm we must believe are similar in all forms of life. There is then in the yeast plant digestion of foods by intracellular enzymes. It it probable that there is a separate form of enzyme for the protein digestion and another for the carbohydrate. The digestion of the foods must be followed by a series of up-building stages which finally result in the food becoming protoplasm. The yeast does work in growing new cells and causing fermentation, as in bread, where the temperature is raised by the fermentation process. This requires energy and is an outgo from the cell. To this may be added carbon dioxide and nitrogenous wastes, although these wastes are masked in part by the presence of other substances in the culture solution.

BACTERIA.

Relationships.—There has been much discussion in the past as to the general relation of the bacteria, whether they should be grouped with the plants or the animals. They are related more closely to a group of algæ known as the blue-green algæ than to any other definite group of plants or animals. Their method of locomotion, and in some instances the manner of spore formation, reveals well-recognized protozoan traits. In the main they are best regarded as plants because of their usual power of living without already prepared protein food and because of their method of reproduction. In their

general physiology they are more like fungus plants and so are classed under the fungus term (mycetes) as *schizomycetes.*

Morphology.—Bacteria appear in three general shapes—the straight rod (bacillus), the bent rod (spirillum) and the sphere (coccus or micrococcus). "There are spherical forms of wide difference in sphericity, rod forms with great variation in length and diameter, and spiral forms having from a fraction of one spiral to many spirals. Furthermore, spherical forms may become piled upon one another so that colonies result, and rods may be jointed in such a way as to construct filaments. Within these groups many species of bacteria are known. One high authority, Migula, considers that there are 1272 distinct species of bacteria, most of which belong to the bacillus type." (Bergen and Caldwell.) Some single species such as *Bacteria*

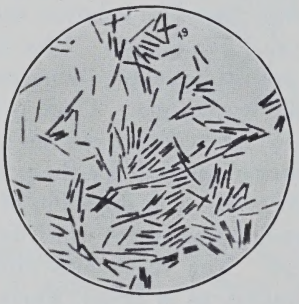

FIG. 88.—Long slender bacilli. × 1000 diameters. (After Park.)

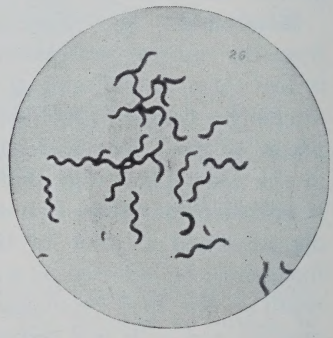

FIG. 89.—Very large spirilla. (After Park.)

pestis and *Bacteria diphtheriæ* exhibit considerable variation when studied under different conditions of growth, appearing first in one shape then in another. Such changes are, however, never permanent, but they illustrate the fact that the morphology of bacteria is not a safe method upon which to determine species.

Size.—"The bacteria were formerly spoken of as the smallest of living things, but since the recognition of ultramicroscopic organisms it is necessary to be more specific in characterizing their dimensions. The unit of measurement in microscopy is the micron (μ) or micromillimeter. This is 0.001 of a millimeter or approximately $\frac{1}{25000}$ of an inch. Applying this unit to bacteria we find that the micrococci and the short diameter of the bacilli and spirilla average about 1μ. The micrococci vary in diameter from a small fraction of a

micron to 3 or 4 μ. The bacilli are sometimes very small, as the influenza bacterium, with a width of 0.2μ and a length of 0.5μ, and sometimes very large, as for example the *Bacteria anthrax*, with a width of 0.2μ and a length of 5.2μ. The spirilla average about 1μ in diameter, but may be as long as 30 or 40μ." (Frost.)

Structure.—Bacteria are extremely simple plants and are regarded by many as the simplest known living things. The cell wall is usually surrounded by a slimy or gelatinous capsule and is not like the cell wall of the higher plants, which is composed of cellulose. Their diminutive size prevents one from learning very much about the cytoplasm. There is no distinct nucleus. The essential part of this organ is believed to be represented by certain granules. From the cell wall in some species a number of cilia or flagella project which are used in locomotion.

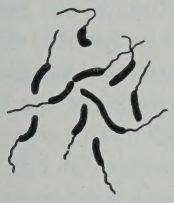

FIG. 90

FIG. 91

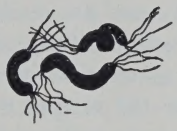

FIG. 92

FIGS. 90, 91 and 92.—Fig. 90, spiral forms with a flagellum at only one end; Fig. 91, bacillus of typhoid fever with flagella given off from all sides; Fig. 92, large spirals from stagnant water with wisps of flagella at their ends (*Spirillum undula*). (After Abbott.)

Motility.—The organs of locomotion are used by the bacteria in moving from place to place. "Some dart with great rapidity, others move slowly; some move in straight lines, others wobble, but any particular character is quite constant, and many of the bacteria may be recognized by their characteristic movements. Their rate of movement varies greatly with the species. As they are viewed under the microscope their motion seems very rapid. The typhoid bacillus has been estimated to travel 2000 times its own length in an hour, while the cholera spirillum may go 45 times as fast. It is probable that their rate is relatively little greater than that of a trotting horse."

Reproduction.—"This is accomplished by means of binary fission. When a bacterium has reached maturity fission begins. This change in the cell is not customarily regarded as preceded by any

series of changes comparable to karyokinesis (mitosis) in the higher cells, since no nucleus in the ordinary sense has been demonstrated in the bacterial cell. Division begins by an invagination of the protoplasm in the middle of the cell, which proceeds until the cell protoplasm is completely separated. The cell wall then grows in and finally splits, forming the two ends of the new cells. These new cell walls are formed at right angles with the long axis of the cell in the case of the bacilli and spirilla, except in rare instances. In the case of micrococci the throwing of the cell wall across one diameter is quite as economical as any other and may therefore proceed in any direction. Migula makes a considerable point of the fact that bacilli and spirilla elongate before division and micrococci divide before they elongate, and this is the criterion which he would use to separate these two-form types. A generation among the bacteria is from one division of the cell to another. This is sometimes very short, in fact, only twenty to thirty minutes. Many of the bacteria after a half-hour's time have grown from newly formed cells to maturity and are ready to divide again. This makes it possible for bacteria to multiply with great rapidity, and if we know the length of the generation in a particular bacterium it is easy enough to estimate the rate of multiplication, at least theoretically. It is, of course, quite impossible for the bacteria to maintain their theoretical rate of growth for any length of time because of the formation of by-products, but they grow with enormous rapidity, as is shown in cultures and in the changes which they bring about in nature, such as the production of fermentation and the generation of toxins." (Frost.)

Under certain conditions a considerable number of bacteria form spores (endospores). The protoplasm is broken up into a number of bodies within the cell, which are then called endospores. Their chief value seems to be to enable the bacteria to endure unusual and unfavorable conditions. In this condition bacteria possess remarkable powers of resistance.

Zoöglea.—The mother of vinegar illustrates a special habit of certain bacteria. The cells secrete a mucilaginous substance that causes them to cohere in great numbers. In some instances this condition represents a stage in the life history, while in the vinegar it is induced by the formation of a certain amount of acetic acid.

Metabolism.—Fischer divided bacteria into three groups, according to the nature of their metabolism. (1) Bacteria which are like the green plants in requiring neither organic carbon nor organic nitrogen.

These are the so-called prototrophic bacteria, which possess the remarkable property of being able to build up both carbohydrates and protein out of carbon dioxide and inorganic salts (page 132). (2) Bacteria which need organic carbon and nitrogenous compounds. These are called the metatrophic bacteria. (3) The paratrophic bacteria which live as true parasites and can exist only within the living tissue. This group cannot manufacture their own food and are like animals in this respect. The metabolism of bacteria may then show all of the phases already described for green plant cells and for animal cells as well as certain additional phases. The food is absorbed directly through the cell wall and is as varied as is their habitat. There seems to be no form of organic substance living or dead that may not serve as a source of food supply for bacteria, so that the enumeration of their foods becomes practically impossible. A special phase of the metabolism of bacteria is illustrated in their relation to nitrogen compounds. Nitrogen in an uncombined state cannot be used as food energy by most plants. It is obvious that the amount of ammonia, nitrites and nitrates would soon become exhausted unless there were some way of supplying more of the nitrogen compounds. Many of the soil bacteria are prototrophic in habit and carry on the important work of combining the free nitrogen into a form that can be used by other organisms. The several nitrogen combinations are effected through the agency of several kinds of bacteria. There are also bacteria which live in the roots of certain plants, like clover, beans and peas, which are able to utilize the nitrogen of the air. All of the higher forms of plants and all of the animals are dependent upon microscopic bacteria for their nitrogen. It would be very strange if the character of metabolism which is so fundamental in living things should be essentially different in bacteria; it probably is not, and so the usual steps in assimilation and dissimilation may be assumed to take place in bacteria. During this process enzymes are utilized and toxins produced.

Enzymes and Toxins.—"Among the most interesting and least understood products of microbial action are the enzymes and the toxins. These two groups are related in many respects. Toxins and enzymes are formed by the cells in such small quantities that they would never have been discovered by ordinary chemical means were it not for the unusual effects which they produce, the enzyme acting upon food substance and the toxins acting physiologically upon organisms. Toxins and enzymes are chemically unknown." (Hahn.)

Zoötoxia of the rattlesnake is the best-known animal toxin, while phytotoxins in plants are more common. Toxins and enzymes are both very sensitive to heat, light and certain chemicals. Both of these bodies must be defined in terms of what they do.

Fermentation.—The organized ferments all employ the same general method to effect changes in the substances upon which they act. The change due to these minute plants, bacteria and yeast is very great, and yet it can nearly all be reduced to a process of fermentation. In the ordinary processes of fermentation the chemical compound is simplified. This is easily understood from the following:

Sugar.		Yeast or bacteria enzyme.				Alcohol.		Carbon dioxide.
$C_6H_{12}O_6$	+	?	?	?	=	$2C_2H_6O$	+	$2CO_2$

Alcohol.		Oxygen.		Acetic bacteria enzyme.				Acetic acid.		Water.
C_2H_6O	+	O_2	+	?	?	?	=	$C_2H_4O_2$	+	H_2O

In this transformation through the action of the yeast enzyme and acetic bacteria enzyme the sugar molecule has become much simpler and the ultimate result is a substance entirely different from sugar, namely, vinegar. The changes are chemical in their nature. It is difficult to make any classification of ferments that is not open to criticism. There are the intracellular and extracellular enzymes that act upon the carbohydrates, proteins and fats; these with the oxidizing and reducing enzymes may serve, however, to give a working classification.

Our Debt to Pasteur.—On December 27, 1822, there was born of humble parentage in the village of Dole, in the Jura, a boy destined to make the discoveries that placed the study of many of the ills of mankind on a scientific basis for the first time. If greatness is measured by showing mankind how to understand Nature's processes and their relation to man's happiness then Pasteur deserves to stand among the foremost of all ages. His discoveries center around the cause of fermentation, the nature of disease and the part played by microörganisms in causing these important conditions.

Primitive man had observed and had utilized fermentation in the preparation of wine, vinegar, bread and cheese from the earliest records of the human family. During these early periods, there are occasional records of men theorizing about the causes that made bubbles rise in fermenting grape juice as it was being converted into wine or as the distending dough of the leavened bread was made ready for baking. During the sixties the wine industry of France suffered severely because the wine became too acid, unpleasant to

taste, ropy or oily. Pasteur had studied fermentation until he was certain that yeast furnished the only ferment essential in the conversion of sugar into alcohol. When he examined these diseased wines, he found in all cases that they contained some other ferment organism than yeast. By this simple observation, Pasteur established for the first time a definite cause for a specific condition in these diseased wines.

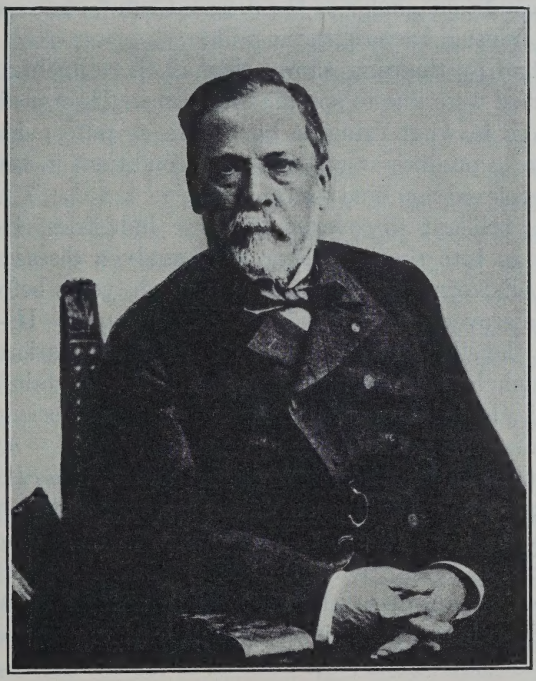

FIG. 93.—Louis Pasteur "Chance favors the prepared mind."

Since wine is acid, Pasteur quickly saw that the growth of these foreign germs might be checked by heating the wine to a temperature of about 56° C. and maintaining it at this temperature for only a short time. The low temperature and the shortness of exposure permits the oxygen in the wine to remain and does not interfere with the ripening process and does not depreciate the value of the vintage. It therefore became the custom to heat wine to the temperature just mentioned and while this does not wholly destroy the bacteria it is sufficient to prevent their development. This method of treating wine is now practised in all wine-producing countries and is known

as pasteurization. This is the same process that is applied to milk in preparing it for use today.

Later, German beers were studied and their manufacture standardized by devising a means of selecting pure yeast. Then the manufacture of vinegar came under his searching analysis and the double fermentation process was recognized and means for regulating it devised. Sour milk, due to lactic acid bacillus, often becomes bitter or ropy, a condition similar to the diseased wines and caused by the presence of unusual bacteria in the milk.

Pasteur had by this time shown that all the fermentations which he had studied were due to specific organisms. He was able to grow each of these in what came to be known as pure cultures. This enabled him to produce at will the same conditions in wines or milk that had perplexed mankind for centuries.

After his brilliant discoveries in these industries, Pasteur was selected to go into southern France to study a disease prevailing among the silkworms. This problem took six years before the real cause was discovered and remedial measures found. His success in eradicating the silkworm diseases led to an investigation of chicken cholera which he soon showed to be due to a certain bacterium. These studies laid the foundation for the next great scientific step in the study of disease, namely, its prevention.

For centuries anthrax had been a most destructive disease among domestic animals especially among sheep and cattle throughout Europe. As early as 1837 a microörganism had been found in the blood of animals dying from this disease. This bacterium had been studied and its causative relation to the disease demonstrated by Davaine and others. Pasteur inaugurated a line of experiments in order to determine whether the anthrax bacillus could be attenuated and made to serve the purpose of a vaccine. He succeeded in accomplishing this in two ways. First, by growing the organism in the presence of an antiseptic such as carbolic acid strong enough to inhibit and modify its growth but not strong enough to kill the organism. Another method of attenuation consisted in growing the cultures at a temperature of 42° C., somewhat higher than that of the animal body. He found that when this was done through several generations the organism is so attenuated that it produces only a mild disease in animals from which they soon recover and after which they are wholly immune to virulent cultures. Probably the world has never seen so theatrical a demonstration of a scientific experiment as that made by Pasteur and his assistants on vaccination for anthrax at

Melun. Having been convinced by experiments upon laboratory animals that he had a certain vaccine for anthrax and being continuously annoyed by criticism, he offered to make a public demonstration. A flock of sheep and a herd of cows were placed at his disposal and on a certain day there assembled at this farm many scientists and farmers. Healthy sheep and healthy cows were vaccinated. At an appointed date later the assembly came together at this place and all the sheep and all the cows were inoculated with virulent cultures. Two days later the assembly was called together and while every unvaccinated animal was dead or dying there was no mortality among the vaccinated.

The results of Pasteur were not accidental but reflect his famous saying "*Chance favors the prepared mind*" for he was well trained in the scientific method of observation and deduction before he began these remarkable studies. Dr. Vaughan from whom these facts are taken sums up the significance of his work as follows: Great as were the researches of Pasteur they were greater still in the possibilities which they have opened up, Pasteur discovered the path which leads up the mountain of human achievement. He pointed out the way by means of which the race might wholly free itself from the infectious diseases. He led the world high up this mountain path, preaching as he did "Let peace be among you. Let science lead you. Under these conditions you may be able to reach the mountain peaks of human perfection." Under his guidance the world traveled far. In every land where his teachings were followed mortality and morbidity rates fell, the average life was prolonged, greater freedom from illness was secured, higher intellect developed. Under guidance we reached the hills where we were able to look down upon the pestilential marshes which he had left.

Some Other Ferments.—In addition to the ferments discovered by Pasteur, others since then have been discovered until their study requires advanced courses and their application to the varied relations of man in Nature is manifold. Here are found under the general heading of ptomaines some of the most violent poisons known. One of these produced by Bacillus botulinus occasionally found growing in sausage, meat, fish and vegetables is so poisonous that 1 cc according to its discoverers, Drs. Bronfenbrenner and Schlesinger, would depopulate the earth. Fortunately contamination of foodstuffs by this bacterium is not common and when the poison is present it is detected readily by the putrid odor of the food. Boiling usually destroys this poison.

Spontaneous Generation or Abiogenesis.—The view that life could come into being without the influence of preëxisting life or from inorganic matter was held for some twenty centuries, from Aristotle, 325 B.C., to Tyndall, 1876. For the ancients there was no difficulty in explaining the occurrence of new animals as complex as insects or even fish. The grotesque extremes to which this easy way of accounting for living things was carried is illustrated by both Virgil and Ovid, who described bees swarming forth from the putrid bowels of the recently killed steer. Frogs, toads, rats and fish were easily conjured from the mud of ponds and streams by the vivifying action of the heat of the sun. Among children and ignorant persons there still lingers a belief that a horsehair placed in water may become a living worm, as well as other similar crude notions about the origin of living things. This idea that life could not come from non-living matter was first successfully questioned by Redi, 1680, who proved that maggots would not grow in meat if flies were prevented from laying their eggs on the meat. Huxley says of Redi, "The extreme simplicity of his experiments and the clearness of his arguments gained for his views and for their consequences almost universal acceptance."

Seven years after the experiments of Redi, microscopic animals and plants were discovered and the theory of spontaneous generation took on a new lease of life, as it was used now as an explanation for these minute forms of life. The Italian, Spallanzani, 1777; the Frenchman, Pasteur, 1864, and the Englishman, Tyndall, 1876, are the three great men who successfully devised experiments that conclusively demonstrated that microöorganisms did not arise spontaneously. These experiments which established the theory of biogenesis for all the forms of life which are known to science should be read in this connection.

The Fate of Dead Organisms.—Ultimately all forms of life die, and yet the surface of the earth is not cumbered with them as would be the case if they remained intact after death. These same organisms in life, particularly the animals, give off wastes in the form of excretions together with the indigestible residue that is subject to the same transforming changes as the dead organism. During life both the plant and animal produce in their bodies insoluble substances which are of no immediate use after they cease being parts of a living organism. These various substances are transformed by either the slow changes incident to weathering such as frost, wind, rain; or action of microörganisms such as the fungi. This particular group of fungi live in dead organic matter which gives to them the general

name of saprophyta. The saprophytic fungi feed on some of these organic wastes and on the dead bodies. This continues through a longer or shorter period until there exist a number of free chemical elements in the place of the organism. The insoluble substances of the dead organisms have been returned to nature and the chemical elements have been relieved and set free. None of them have been destroyed.

The Energy Cycle.—The urea waste of animals is broken down into simple ammonia compounds. Certain bacteria can use these simple nitrogen compounds and in doing it form a nitrous acid compound, known as a nitrite, that is now in a form that other bacteria can utilize in their metabolism. There are also the nitrogen-fixing bacteria which take free atmospheric nitrogen, and uniting it with the hydrogen and oxygen from water, produce complex nitrogen compounds. The several kinds of bacteria furnish for the green plants their supply of nitrogen in the chemical form required by them. There is thus a definite cycle through which the nitrogen passes. Carbon enters into the living protoplasm through the union of carbon dioxide and water under the influence of chlorophyll. It is evident that this is the ultimate source of carbon for all life. When the foods manufactured by plants are utilized by plants or animals one of the final products is carbon dioxide which is again returned to the air. It is now ready to repeat its journey under exactly the same limitations. As it unites to form starch, oxygen is released and we have a third element ready to begin again its cycle.

It is thus seen that the elements that enter into the living protoplasm either as simple or complex compounds pass through a fairly regular cycle. Before energy is available for metabolic changes, energy must have been provided in the compound that is to be used. The several ways in which this is accomplished are now well understood. No one can tell how many times the oxygen that we are breathing has been a part of other living things nor for how long a time. All that we know is that we could not live without it. It does not matter how often nor how long an element is used so far as its usefulness to future living things is concerned, provided it is properly combined so that the plant or the animal protoplasm of perhaps a thousand years hence can utilize it. We may feel then that there will always be plenty of the necessary chemical elements to support life, because living matter does not destroy them and cannot exhaust them, but simply holds them in the living relation for a longer or shorter period.

Summary.—1. The ferment organisms secure their energy for living either (*a*) like green plants; (*b*) like animals or (*c*) possess metabolic characteristics that enable them to utilize inorganic compounds. They are more complex than carbon dioxide and water and simpler than the proteins required by animals.

2. Whether these several organisms secure their food energy from dead organic matter and are hence known as *saprophytes;* or from living matter and therefore termed *parasites;* or from the more complex inorganic compounds, each exhibits the same manifestations of life as the animal or green plant.

3. The ferment organisms have a vital relation to human welfare as a regular part of their life processes. They not only contribute in an advantageous way to our daily life in the making of bread, butter and cheese, but on the other hand their activities cause food to spoil and consequently make necessary refrigerators and methods of canning. A third phase of their relation is the fact that some of these organisms are a specific cause of sickness and death to plant, animal and man (see Chapter XXVII). Important as these relations to man are, they are relatively insignificant as compared to their relations (*a*) in the releasing of energy from the insoluble organic compounds; (*b*) in the recombining of these elements into chemical bodies that green plants can utilize; because they in turn manufacture chemical bodies (proteins, carbohydrates and fats) that are indispensable to man and animals.

4. The significance of the interdependence of organisms has a clearer meaning as these energy cycles are analyzed. No organism can live unto itself alone.

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CHAPTER XI.

WHAT IS LIFE?

We are now in possession of facts that permit us to ask intelligently the question "What is Life?" In the earlier part of the course, there was no question in your mind about the frog being alive. It was alive because it jumped, swam and breathed. A little closer analysis revealed that these were rather superficial indications of life processes for we also learned that this same frog was alive when it did none of these obvious things as in hibernation. The frog was no more alive when jumping than when taking his winter sleep. The same vital processes take place within the living cells as long as the frog lives. It is these protoplasmic manifestations of life, then, that we have come to accept as the final criteria of "What Life Is." Every unitary mass of living substance that is capable of self-preservation under definite vital conditions reveals these protoplasmic manifestations of life.

The origin of life continues to perplex the scientists of today as it did the philosophers centuries gone by. Did life originate once only or several times soon after the earth took on a substantial form? Careful students of the oldest rocks declare that there is no time when life was wholly lacking after the rocks were formed. This makes the terrestrial span of life extend over aeons of time. It is believed that bacteria were present when these oldest rocks were forming. In this case, then, the bacteria have no rivals in being the first forms of life to leave a record of their early presence on the earth. No one has been able to answer satisfactorily how life first began on the earth so that this "riddle of life" is still unsolved.

The facts that we possess about life *are all verifiable.* There still remains a large mass of facts to be discovered about the chemical reactions of living protoplasm, to name but one of the unsolved problems. New information is being added all of the time and these new facts about life are just the same kind of facts that we now possess. *We have no reason to expect that the future will reveal a brand of facts that do not obey natural laws.* The new discoveries of the future, then, will extend, but not destroy, our information about life. Those who are to have the great satisfaction of extending this boundary line will

employ the scientific method of procedure as each of their predecessors has done and their new facts will also be verifiable.

There has been much superficial comment about the instability of scientific thought. In this connection it is important to distinguish between the permanent body of facts and the hypotheses about these facts.

The facts about life have not changed with the increase in our knowledge. Man's efforts to classify these facts and to draw conclusions from them has constantly changed and will continue to change until life processes are completely understood. During the period while the human mind is attempting to interpret these incomplete facts about life, different men will try to formulate explanations. These explanations will be based upon *what we already know as a means of finding out what is to be known.* Such an explanation is termed an hypothesis. No scientific hypothesis has ever commanded the respect of scientific workers unless it constituted a probable explanation of the facts. No intelligent and fair minded thinker confuses this proper and valuable use of hypothesis with guessing which is a haphazard opinion unsupported by an investigation of facts.

While the origin of life remains unknown, there is no controversy among scientific men as to how present-day animals and plants came into existence, for they can be proved to have been derived biogenetically. The verifiable facts about this phase of life permit but one conclusion to him who reasons honestly. This conclusion is expressed not in the form of an hypothesis but as a fundamental generalization or law of life which has been condensed into one word, *biogenesis, the law that life is generated from life only.*

Organized protoplasm is being studied from every angle that the ingenuity of man can devise. Just what means can he employ as he tries to penetrate further into the details of the changes taking place? (1) There are at his disposal the physical facts about inorganic nature and the inventions of the microscope and photography which enable him to describe the physical properties of protoplasm; (2) there are all the facts and conclusions which chemists have assembled about inorganic nature and the products of organic activities and he must conduct his methods of study along the established facts of this department of knowledge; and (3) he studies the reactions of living protoplasm as such employing the methods of the physicists and chemists in so far as they are applicable and in addition applies specific biological methods such as experimental breeding, grafting, regeneration, etc., the results of which he summarizes under the

biological properties. What has been learned about protoplasm from these three points of view is summarized as follows:

The Physical Properties of Protoplasm.—In 1866 Huxley coined the phrase "Physical Basis of Life" in the assumption that there was a common structural basis for all protoplasm. So far as we can determine, protoplasm is not identical in any two organisms although the differences in appearance are fewer than the similarities.

Protoplasm consists of a number of very complex bodies organized into a single functioning unit. It is neither a liquid nor a solid, but rather a jelly-like substance similar to the white of an egg. Constant changes take place in living protoplasm in which first the liquid condition prevails, to be followed by the more solid state which in turn assumes the liquid state. Physical chemists designate such a condition of matter as a colloid (Kolla, glue); and the liquid state as a *sol* and the solid as a *gel.* The physical changes in living protoplasm are a constant succession of change from the sol to gel to the sol in endless repetition. There is a small amount of elasticity present, for living matter can be stretched and when released returns to its previous shape.

When protoplasm is studied by means of the microscope, it presents a certain appearance. This will vary with the kind of protoplasm being studied and whether it is alive or has been fixed by such chemical agents as picric acid, formalin, etc. Up to the present it has been impossible to give a single physical description of protoplasm that applies to plant and animal, muscle and nerve, or egg and gland-cell protoplasm. The physical picture presented by protoplasm under different conditions of activity and in different organisms has been accounted for by the two following theories:

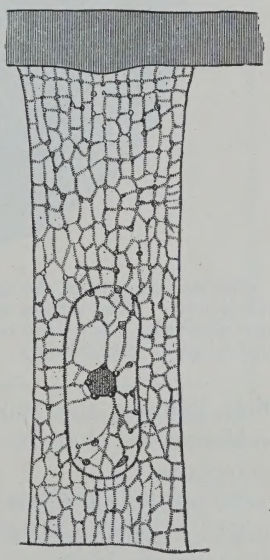

FIG. 94.—Epidermal cell of an earthworm. × 3000. (After Hall.)

1. *Fibrillar Theory.*—The adherents to this theory claim that a distinct meshwork of cytoplasmic fibrils can be made out when suitable treatment is employed, and such terms as spongioplasm, reticulum, filar substances, etc., are used to describe the meshwork. Filling in the meshes there is a structureless sap-like substance.

For some cells and for certain phases of cell activity the fibrillar theory adequately describes the structural conditions of the protoplasm.

2. *The Alveolar Theory of Bütschli.*—This theory assumes that protoplasm consists of two fluids, one suspended in the other. The fluid that is suspended is made up of numerous minute drops which give the appearance of closed chambers or alveoli. The containing fluid is continuous and occurs between these minute alveoli. By mixing rancid oil with sodium carbonate a solution is produced

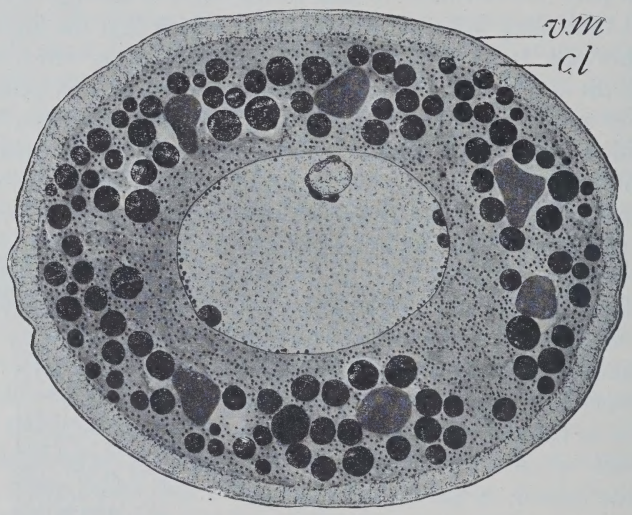

Fig. 95.—Section of the egg of *Nereis*, fixed in Meves's fluid five minutes after insemination. The cortical layer is somewhat reduced. *c.l*, cortical layer; *v.m*, vitelline membrane. Note the several kinds of bodies in the cytoplasm. (From Lillie, in Journal of Morphology.)

that imitates the appearance of protoplasm very closely. The epidermal cell of an earthworm (Fig. 94) is an illustration of alveolar cytoplasm.

In nearly all forms of protoplasm there are variously shaped granules which are the usual particles seen by students. Some of these become so large as to be the most conspicuous physical feature (Fig. 95). We may say that protoplasm consists of an aggregate of fluids which vary in density and which present a wide variety in appearance.[1]

[1] For a recent discussion of the relation of colloids to protoplasm, read Matthews' Physiological Chemistry, chapter v, p. 190.

Chemical Composition of Living Matter.—When life is studied from the chemical point of view the results tell us what chemical bodies are present. No one has been able to write the chemical formula for living matter, and after all these years but little is known of the chemistry of living matter. One of the reasons for this lack of chemical knowledge is that as soon as a chemical analysis is applied to living protoplasm it becomes dead, and science has yet to prove

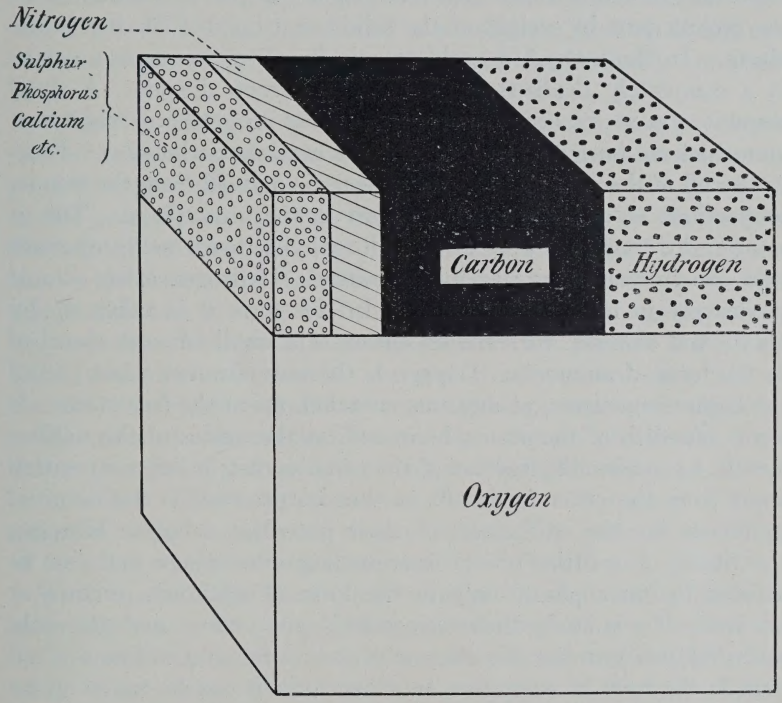

FIG. 96.—Diagram to show the proportionate amounts of the chemical elements in living things.

that the chemistry of dead protoplasm is the same as that of living protoplasm. Whether future research reveals that dead and living protoplasm are essentially the same or not, we already know what chemical elements occur in protoplasm.

There are some eighty-two different chemical elements known to science and not more than twenty-nine of these ever occur in living protoplasm. Twelve of these are but rarely found while four are of frequent occurrence. The remaining thirteen are invariably found

and believed to be essential to life. These are hydrogen, carbon, oxygen, nitrogen, phosphorus, sulphur, potassium, magnesium, calcium, iron, sodium, chlorine and silicon. These elements are the most numerous in the rocks, water and atmosphere. But the amount of these elements, even those that are essential to life, found in an organism bears no relation to their abundance in nature.

The following summarized account from Starling of the most important elements shows their relations in Nature: "Carbon forms the greater part by weight of the solid constituents of living protoplasm. In the inorganic world practically all of the carbon occurs in a completely oxidized form, namely, carbon dioxide. A small amount, 4 parts in 10,000, is present in the atmosphere, while vast quantities are buried in the crust of the earth as carbonates. Practically all of the carbon in organic tissues is derived from the minute proportions of carbon dioxide present in the atmosphere. This is combined through the work of the chlorophyll into carbon compounds that can furnish energy to living matter. Hydrogen exists almost exclusively in the form of water. In this form it is taken up by plants and animals, with the exception of a small amount absorbed in the form of ammonia. Oxygen is the only element which, in all the higher organisms, at any rate, is taken up in the free state. It forms one-fifth of the atmosphere, and, as the oxides of the various metals, a considerable fraction of the earth's crust; it takes a position apart from the other foodstuffs in that its presence is the essential condition for the utilization of their potential energy. Nitrogen constitutes four-fifths of the surrounding atmosphere and can be utilized by most plants only in the form of ammonia, nitrites or nitrates. To animals these compounds are useless and the only source of nitrogen for this class is protein. Sulphur is found in all soils in the form of sulphates, in which form it can be taken up by plants. Iron, though forming but a minute proportion of the material basis of living organisms, is, nevertheless, indispensable for the maintenance of life. Phosphorus is absorbed by the plant as phosphates."

Of the thirteen elements always found in protoplasm, six are more abundant. These are the ones that make up the structure of the protein and carbohydrate molecules. Carbon, hydrogen and oxygen are the only ones that are found in that part of organic foods classed as fats and carbohydrates. The protein molecule is much more complex and only empirical formulas can be given, but in these there always occur carbon, hydrogen, nitrogen, oxygen and sulphur. One

of the simplest plant proteins, the crystalline vitelline of the squash, is written $C_{292}H_{481}N_{90}O_{83}S_2$, while the form of the animal protein, hemoglobin, is supposed to be about $C_{712}H_{1130}N_{214}O_{245}FeS_2$. Through the foods containing these chemical elements, organisms secure most of their energy for growth and bodily maintenance. The remaining elements found in protoplasm exist in small quantities and are usually brought to the living protoplasm in the water. It may be said that carbon, hydrogen, nitrogen and oxygen are the most important of the elements found in protoplasm because living protoplasm must be constantly supplied with foods chiefly composed of them.

When the biologist applying chemical methods of study learns just what chemical elements or combination of chemical elements is present in protoplasm he destroys that which we describe as the life of the protoplasm. He has disorganized the relations that existed between all of these chemical bodies which results in death. From this we are permitted to infer that protoplasm is not a simple chemical compound nor a mixture of chemical elements but an organized body that possesses biological properties that are not present in the individual chemical compounds. In just what manner these several chemical elements and bodies are organized in protoplasm is unknown.

When certain chemicals like iron for example are wholly withdrawn from living protoplasm, its normal living functions are altered or inhibited. The minute amounts of the internal secretions which are responsible for profound changes even in man indicate something of the intricacy of the organization of protoplasm.

Water is one of the most conspicuous of the chemical bodies found in protoplasm: In the jelly-fish constituting 98 per cent of the entire animal and even in man being present as more than half of the total, 58.5 per cent. Water is present in all parts of the body of man; enamel, for example, contains 2 per cent, the gray substance of the brain 86 per cent, muscle 75 per cent, saliva 99.5 per cent.

The Biological Properties of Protoplasm.—Neither the chemical composition nor the physical appearance of protoplasm furnishes an explanation of living protoplasm. As already stated, when chemical bodies unite to form protoplasm there is produced a substance which has certain properties or characteristics that enable one to distinguish between that which is alive and that which is not. These are defined under the following eight headings:

1. *Relation of Life to the Living Body.*—Life does not reside in any one structure in the body of plants and animals but is present in all

of their parts. It cannot be measured, photographed or weighed. Even a child can tell a dead animal from a live one, but no one can isolate that which makes an organic being living. This general

FIG. 97.—Redwood trees in the foreground with sugar pine, bull pine and white fir in the background, Sierra National Forest, California. The redwood trees are the oldest and largest living things known to science. Illustration furnished by the United States National Museum and published with their permission.

diffused, immaterial condition, life, may be driven from the organism by a multitude of causes and leave all of the parts intact, as when life was present—in some instances the several parts may remain alive for hours or days after life has departed. This is well illustrated by

taking the heart of a frog from the recently chloroformed animal and placing it in salt water. The heart now begins to beat in a rhythmic fashion. Living cells can be taken from various animals, and when placed in an artificial culture can be kept alive for months at a time. In one instance connective-tissue cells isolated from the heart of a chick embryo have been kept alive for seven years. Under such conditions they are entirely separated from the living animal; but while able to grow under this abnormal condition, they cannot give rise to a new individual like the animal or plant from which they were taken.

2. *Size of Living Bodies.*—The size and shape of living bodies cannot be stated in any general expression. Some are so small that the highest power of the microscope has failed to reveal them, while the giant redwood trees tower above all other living things by many feet (Fig. 98). Between these two extremes are found a multitude of sizes, each of which is characteristic of a given species. Animals have never grown to such large size as some of the trees, although some of the fossil forms were nearly one hundred feet long (Fig. 98). When a given kind of plant or animal comes to have a certain size and shape there are only minor variations from year to year, as both appear to have become fixed for a given species and are continued from generation to generation by heredity.

3. *Age of Living Bodies.*—A number of the unicellular organisms retain their individuality for not more than thirty minutes under normal feeding conditions, while the great redwood trees have retained their individuality for possibly twenty centuries, and between these two extremes are to be found all gradations. It is customary to speak of the longevity of a group of plants in such terms as annuals or perennials, which means that certain species have come to have a certain fixed period during which they live. One of the real problems in biology is to explain old age. It is now conceded that this has come to be a natural stage in the life of all multicellular organisms; but why should one come to have the ability to live for centuries and a closely related form but a hundred years? All organisms pass through three stages—youth, maturity and old age—which are intimately associated with organic maintenance, but even when the body is supplied with suitable food it grows old.

4. *The Cell and Living Protoplasm.*—The accumulated observations of all the scientists clearly demonstrate that life is to be found only in protoplasm; and also, that this protoplasm is always to

be found existing in structures of definite size and shape, to which the name cell has been given (page 72). This is one of the most obvious facts thus far established in this course (see also Heredity, page 269).

5. *Reproduction and Life.*—All of the observations of man indicate that new forms of life are produced by living organisms. In so far as the present varied life is concerned, each species of plant and animal is produced by parent forms of the same species. Reproduction, while a universal process in life, has become highly specialized, so that only a frog can come from frog eggs and *Rana pipiens* cannot be derived from *Rana catesbiana*, although both of these frogs belong to the same family, the *Ranidæ* (page 23).

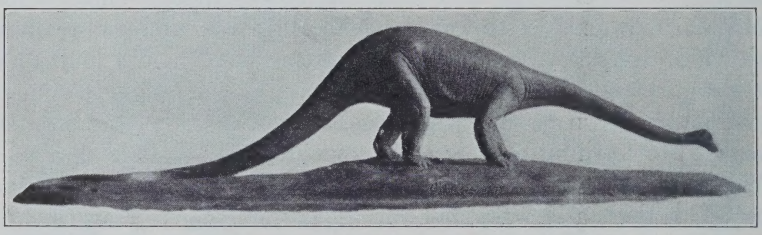

FIG. 98.—*Diplodocus carnegii* Hatcher, from modelled restoration by C. W. Gilmore This reptile was probably 87 feet long and 15 or 16 feet high at the hips. One of the largest animals thus far known to science. Although this huge animal is known only through a study of its fossil remains, it can be confidently stated that it possessed all of the fundamental characteristics of modern animals. Photograph furnished by the United States National Museum and published with their permission.

6. *Growth and Life.*—Growth is one of the facts of life that all have observed. When the frog was dissected a number of important organs were found. Where did these come from? During the embryonic growth of the frog all of these structures gradually took shape and position in the body of the frog. Inasmuch as the term growth is used to describe the formation of crystals, it is desirable to specify its use in biology: (1) Crystals grow only in a highly saturated solution of material like the crystal itself, while living things can grow in a weak nutritive solution; (2) this nutritive solution does not contain the chemical compounds found in the living cell, while in the case of crystals the substance of the crystal and its nutritive solution must be chemically identical; (3) growth in living things leads to the production of more living things, while growth in inorganic nature never does. Le Conte succinctly expresses this distinction in the following sentence: "It (organic life) manufactures

materials like itself out of materials wholly different from itself and then uses the product for growth."

7. *The Awareness of Living Protoplasm.*—All forms of living protoplasm respond more or less to changes in temperature, like winter and summer. The habit which certain trees have of shedding their leaves is a well-known example. The small organisms react to the stimuli of their environment in a rather definite manner, as the reactions of the paramecium indicated. In the higher animals a definite specialization in the form of the nervous system occurs which takes on the work of receiving and transmitting stimuli, and, with the assistance of the muscles, producing a definite coördination (irritability, conductivity and coördination) (page 91).

8. *Maintenance of Life.*—Not all young plants and animals grow to maturity nor do all adults continue to live to old age. Death is one of the most obvious facts connected with life and occurs at all ages. The keeping of the organism alive is a process distinct from growth, for it continues long after growth ceases. The technical term of metabolism (defined on page 61) is used to describe the intricate and complex changes that take place in living protoplasm as the individual organism passes from the embryo through youth to maturity and old age. Associated with the maintenance of living protoplasm is the production of those bodies to which the name of ferment or enzyme has been given.

Life or living protoplasm is thus seen to be composed of certain limited chemical elements having a characteristic physical appearance. The biological properties are distinctive for matter in the living condition and are not found united in any of the inorganic bodies. Any new creation of life that may be announced from time to time must have all of these characteristics if it is to be identified with the life which now exists. With the great amount of specialization that is being carried on it is pertinent to urge that life should be studied as a whole and not as so many parts, for it is really the whole life that determines the several parts and processes. It is also desirable to urge that for the biologists LIFE is the fundamental reality and not the physics or chemistry of it.

PART III.

PLANT AND ANIMAL TYPES ILLUSTRATING BIOLOGICAL PRINCIPLES.

CHAPTER XII.

SOME LOWER PLANT TYPES.

Thallophytes.—Probably the most important thing about a plant is the way that it gets its food. The normal plant, whether it be simple or complex, is one that can gain its food from Nature. It is not a dependent organism. To this fundamental conception in regard to the nature of a plant should be added another, namely, that there has been an evolution in plants along divergent lines, resulting in the formation of plant groups, in which the genetic relations are complicated. In this process of evolution, however, some of the structural characters of the simple plants are to be found in the higher, although greatly modified.

In the thallophyte phylum are placed the simplest forms of plants. The body is a thallus and there is no root, stem or leaf in the usual sense. The cells of the plant are similar and tissues are absent except as noted below. In some members of this group root-like processes, known as holdfasts, are developed. Many of these plants are fragile, having the cells united into linear series, while others are like the brown kelp, tough sea-weeds, many feet in length.

As the classification indicates the thallophytes are composed of many normal chlorophyll-bearing plants, the algæ, and the divergent and dependent group of fungi, many of which show definite algal affinities. The fungi live as parasites, saprophytes and symbionts, and their relations to disease in plants and animals is so important that a separate course is necessary to present even the general facts of disease in fruits, in grains, in trees, in domestic animals and in man.

The life cycle of this group is relatively simple as compared with the remaining phyla of plants, and this serves as their chief distinguishing character rather than the nature of the thallus, for some of the higher plants have thalloid bodies, and some algæ have a stem-like and leaf-like structure, as complicated as that of mosses, and a well-defined system of tissues. This group, then, is especially interesting because it shows the beginning of tissue differentiation and the origin and earliest expression of sex and sex organs.

CHLOROPHYCEÆ, THE GREEN ALGÆ.

This is the largest class of the algæ, containing more than 8000 species. They are found in both salt and fresh water as well as on land. Of the simpler plants, several members of this class are among the most common. The familiar "pond scum" or "frog's spittle" in the ponds and slow-running streams, as well as the green covering on moist surfaces of the earth, in pots, etc., called "green felt," are two of these plants that are first studied. The former is some form of spirogyra and the latter vaucheria.

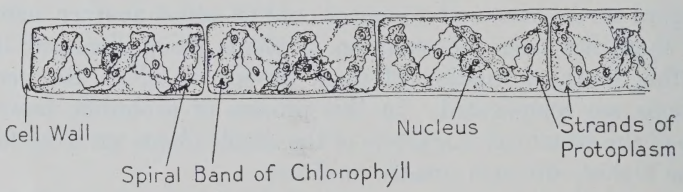

FIG. 99.—Spirogyra as the cells appear except when conjugating.

Spirogyra.—"Pond scum" consists of many long, silky threads. Each thread is a complete plant of several cells attached end to end. The green color varies. Each cell of spirogyra is large and cylindrical in shape. In each cell there are one or more spirally arranged bands containing chlorophyll; these are the chromatophores or chloroplasts; their number and their manner of coiling depend upon the species. The cytoplasm is distributed in the cell as a thin layer next to the cell wall. Fine threads of cytoplasm extend from all sides to the nucleus. The center of the cell is occupied by sap. In the chloroplasts are several pyrenoids which are the special centers where the starch is manufactured (p. 132). Spirogyra is composed of nearly 98 per cent. water, and yet the vital processes of the plant are adequate to enable it to manufacture food. The masses of

spirogyra are frequently full of bubbles of oxygen that are given off in this vital process.

Spirogyra reproduces by normal cell division, and the new cell wall forms at right angles to the length of the filament. Such divisions cause the filament to increase in length. This form of cell division takes place very rapidly. The second form of reproduction is important because it illustrates an early stage in the development of the sexual method. The cells of two plants that lie near together form connecting bridges (Fig. 100, *A*), which are tubular outgrowths that eventually furnish a continuous passage between the connecting cells. The protoplasmic contents of one cell flow into the other and the two masses unite into a single body, which has become much

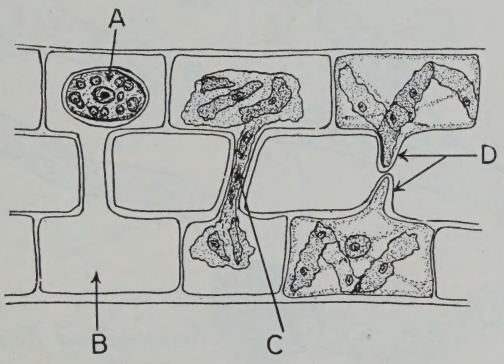

FIG. 100.—*Spirogyra* conjugating. *A*, zygospore; *B*, empty cell; *C*, protoplasm flowing from one cell into another; *D*, each cell is forming an outgrowth which unites to form a passageway between the two cells.

reduced in size. A thick cell wall is secreted around this body, which is termed a spore. In view of the fact that the masses were formed by the fusion of similar cells the spore is called a zygospore (a yoked spore). The two protoplasmic masses that fused are called gametes. "Cells that unite to form sex spores are called gametes; hence a zygospore is a sexual spore that is formed by the union or conjugation of similar cells." As the parent plants decay the zygospores escape. A period of rest follows, caused by a drought or winter, after which each one begins to grow into a new spirogyra. The formation of this reproductive spore is of obvious advantage.

Vaucheria.—This is the common "green felt" which is usually found growing on the soil, although it may be found in the water.

The filaments are coarse, much longer than spirogyra, and branching. Plants taken from the soil usually penetrate it slightly. The youngest branches are the greenest. The whole filament consists of a single cell with numerous nuclei scattered throughout its length. This arrangement may have arisen through the failure of the dividing cell to form walls. Such a condition is termed a coenocyte or syncytium. The cytoplasm of vaucheria contains numerous chloroplasts, which indicates that it has the power to manufacture an abundance of food.

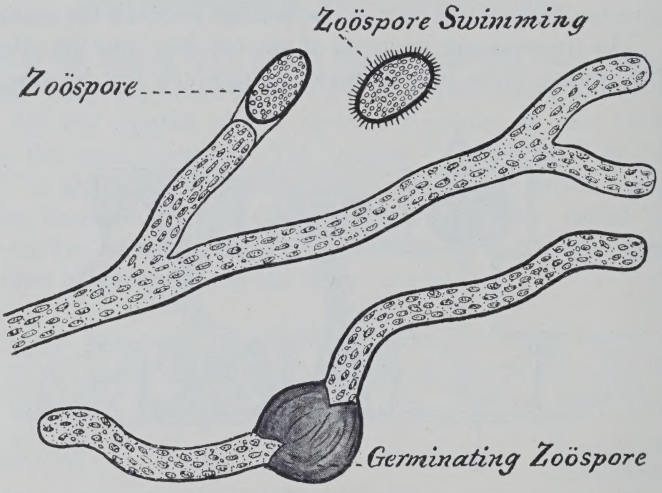

Fig. 101.—Vaucheria—asexual reproduction.

Asexual reproduction accidentally takes place when the old end of the filament dies, and as it decays sets free the branches which now become separate plants. Asexual reproduction normally begins by the formation of a cross-wall in one of the branches. The isolated protoplasm becomes transformed into a large zoöspore (Fig. 101). This body escapes into the water and swims about for a time, then grows into a new vaucheria. The zoöspore is made up of many cells, although it gives rise to but one plant. Sexual reproduction occurs through the formation of special short branches on the side of the plant (Fig. 102). On this branch one or two large oval masses appear with a beak-like process. The terminal branch in the figure is long and coiled with a terminal cell cut off from the rest of the branch. In this terminal cell many small cells are formed which escape into the water. By means of long cilia they are able to swim about. One of these cells enters the oval mass. After the union of the two

gametes, a thick wall is formed about the cell which is called an oöspore; after a period of rest it grows into a new plant. The only difference between this process in vaucheria and the conjugation in spirogyra is in the unequal size of the uniting gametes. The large oval mass that receives the small free-swimming gamete is now called an egg or oösphere, while the small free-swimming gamete is a sperm. *The union of the sperm and egg is fertilization.* The special cell which produces the sperms is termed the antheridium, while the cell that produces the egg is the oögonium.

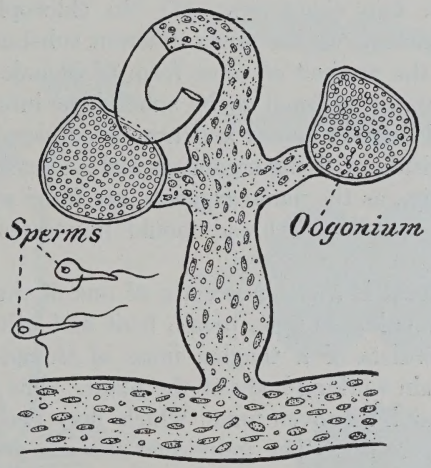

FIG. 102.—Vaucheria—sexual reproduction.

PHYCOMYCETES, THE ALGÆ FUNGI.

The general subphylum of fungi includes one of the largest groups of plants: there are more than 64,000 known species.

The general habitat of this group is well expressed by Underwood as follows: "Whether we are aware of their existence or not, there are in the world about us a vast array of more or less inconspicuous organisms that are known to botanists under the name of fungi. These differ among themselves in size and structure far more widely than do a violet and an oak, and many of them at first sight would seem to bear so little resemblance to one another as to possess no real relationship. Many of them are known more or less popularly under common names such as moulds, mildews, mushrooms, toadstools, puff-balls, rusts, smuts, leaf spots and blights, each popular

name indicating a more or less indefinite group of plants more or less closely related to one another. They grow in every conceivable place where organic matter can be found which will serve as their food, and a moderate degree of heat and moisture are present to furnish the necessary conditions of growth. Decaying fruit or vegetables, oily bones, old musty shoes, wet paper, the dead stems of herbaceous and woody plants, the dead and dying branches of trees, standing stumps and tree trunks and fallen logs all furnish the matrix in which fungi of various sorts, a few conspicuous, many more inconspicuous, thrive and multiply. With all their differences fungi agree in two characters: (1) No chlorophyll. (2) They reproduce by spores. In the many different substances enumerated above, all are the product of some form of organic activity. This permits the habitat of fungi to be subdivided into (1) those that live upon dead organic matter and are called saprophytes, and (2) those that subsist upon living organisms and are known as parasites."

The algæ fungi, as the name suggests, are fungi which are similar to algæ. The well-known bread mould illustrates some of these similarities.

The Bread Mould is a common form of one of the simple moulds that grows in our homes upon bread, fruit and other suitable substances. It consists of a tangled mass of thread-like structures, which is the main working body of the plant. The name mycelium is given to the interwoven mass, which may become quite compact in older growths. The individual threads are called hyphæ. Some of the hyphæ send out special threads which are known as rhizoids and penetrate the nutrient material. The bread mould derives its nourishment directly from the nutrient substances upon and in which it is growing. We may believe that the foods found in the bread are utilized through the production of certain enzymes by the hyphæ. The reason for believing that this is the method is because *Aspergillus niger,* a mould, has the reputation of forming a large number of enzymes; and *Pencillium camemberti* (the chief organic agent in ripening Camembert cheese), according to Dox, produces the following enzymes: erepsin, dulclase, aminase, lipase, emulsion, amylase, inulase, raffinase, invertase, maltase and lactase. The formation of the mycelium takes place by the asexual or vegetative method of reproduction. After a time a number of upright stalks are produced from the mycelium and are called sporangiophores (sporangium bearers). The tip of each upright branch produces a globular sporangium which is full of spores. The walls

of the sporangia burst and the dust (spores) is scattered by air currents.

When the bread mould reproduces by the sexual process, which it does rarely in nature, the process is interesting because it is so similar to spirogyra. The free ends of two hyphæ come in contact (Fig. 104) and end cells are cut off. These two end cells enlarge and eventually unite to form a single spore with a dark heavy wall (Fig. 104). The two cells which contribute to the formation of this spore are similar, and so the resulting body is a zygospore.

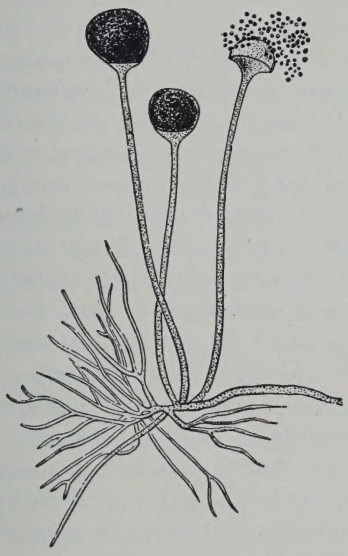

Fig. 103.—Bread mould.

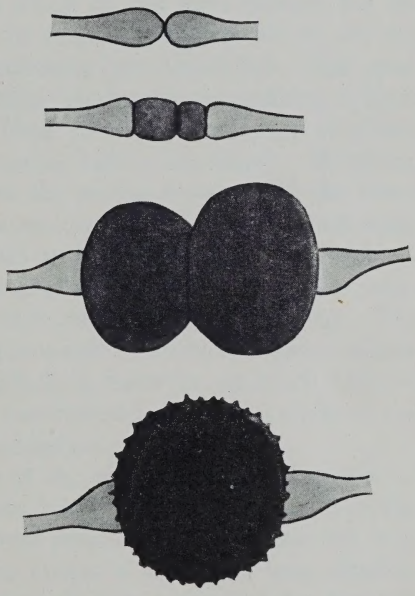

Fig. 104.—Mucor spore formation.

Water Moulds.—There is one very common water mould which lives upon dead insects, fish and other animals. This mould has the interesting habit of thriving either on a dead fish or one that is alive, readily assuming either the saprophytic or the parasitic habit. At times it becomes a serious pest in fish culture. A culture of water mould (saprolegnia) is usually secured by simply dropping a dead fly found on the floor or window sill into a dish of water. There is soon formed a whitish mass of hyphæ growing out in all directions from the insect. The hyphæ on the body of the insect digest such parts as may serve as food, and it is in this way that they are effective

agents in destroying dead animals in the water. The water mould reproduces by the asexual and sexual methods. The water and bread moulds serve to illustrate a type of plant life that has its food already made; they are plants related to certain green plants and they differ from them chiefly in the absence of chlorophyll. This suggests that the habit of utilizing ready-made food is really an acquired habit. More or less closely related to these common moulds are the mildews, rusts and many others less well known.

CHAPTER XIII.

SPERMATOPHYTA—TRILLIUM GRANDIFLORUM.

Spermatophytes.—The division spermatophyta (meaning seed plants) contains not only the groups frequently called "flowering plants," but also other groups which do not have flowers, for the reproductive organs are borne in cones or clusters which are not at all showy, but rather inconspicuous (see Appendix). The spermatophytes have also been called phanerogams (meaning evident marriage) to distinguish them from all the lower groups of plants which are called cryptogams (meaning hidden marriage). However, this separation was made before the sexual processes of the lower plants were understood, for, as a matter of fact, they are much more evident than the complicated ones in the seed plants. The seed is a more significant structure in the group than the flower, so the name spermatophyte has in recent years come into general favor. The seed plant, like the fern, is a sporophyte. There is a gametophyte generation in the life history, which is, however, so much reduced in structure that it can only be understood by a careful study of the reproductive processes in seed formation.

The Seed.—"The importance of the seed in the development of plant and also of animal life can hardly be exaggerated. For the plant it furnishes one of the surest means of reproduction not only because of protective structures, means of dispersal, long vitality, etc., but also because the embryo plant is carried so far forward in its development that it is able to take root and establish itself at once. And further to aid the embryo, the seed is a storage organ of the most condensed forms of food material found in plants. In this respect, also, the seed has proved a most important influence in shaping the habits and in a large measure the evolution of some forms of animal life; for the highest groups of animals live to a very great extent directly or indirectly upon food stored in seeds and certain fruits, finding there some of the richest and most nutritious proteid and carbohydrate foods." (Bergen and Davis.)

The pollen grain of seed plants corresponds to the microspores of pteridophytes and produces a male gametophyte which bears sperm

cells. Similarly, within the ovule of the seed plant occurs a cell which corresponds to the large spore (megaspore) of pteridophytes and which produces the embryo sac in which the egg is formed. In order that fertilization may take place, the pollen grain produces an outgrowth or pollen tube which penetrates the tissues surrounding the egg and carries the sperm cells to the egg.

The spermatophyta have the most perfect expression of root, stem and leaf found in any plants. It is but a short process to perfect the formation of the seed already anticipated, and so the members of this group have become differentiated in solving the life-cycle problem, with the result that they have expanded into a multitude of forms following two lines of evolution, one the monocotyledons, in which the cat-tail flag may be thought of as the lowest and the orchids as the highest; and the dicotyledons, in which a similar primitive and recent display is represented by such plants as lizard's tail and the crowning group of composites.

Trilliums.—The common trilliums belong to the family of plants known as the Liliaceæ, which includes some 2500 species that are widely distributed and extensively cultivated. Among the cultivated species that are familiar are the hyacinths, lilies, tulips, lily of the valley. Asparagus and onions are lilies cultivated for food and the aloes, colchicum and others are used in medicines.

There are several species of trilliums in the United States, of which the wake robin (*Trillium grandiflorum*) is the commonest. Its natural habitat is in or near the woods, where it is frequently found with the painted trillium. Fig. 105 gives a good idea of the habitat of the trilliums.

The entire plant consists of a thick, fleshy, underground stem or rhizome from which arise numerous strong, wrinkled roots, and a leafy flowering stem bearing leaves and the flower. The rhizome lives on for a number of years and so is termed perennial. It is marked by ridges and scars which indicate something as to its age, since each scar indicates where a single flowering stem was attached.

The new leaf stalk arises from the growing end each year. The leaf stem normally bears a whorl of three sessile leaves near the flower. From the center of this whorl arises the flower stalk bearing a flower at its summit (Fig. 106).

The flower is the most conspicuous feature of the higher plants. It has passed through many evolutionary stages before we come to the highly developed flower of the trillium. The parts of this flower

are the calyx, the corolla, the stamens and pistil. The calyx consists of a whorl of three-pointed, green, leaf-like structures. Each individual part is called a sepal. The calyx is thus seen to be made up of three sepals, which are easily recognized as similar to the leaves. While the corolla is made up of structures similar to the sepals, they are wider and white in color. Each member is termed a petal. Within these two whorls of leaf-like structures are found two whorls

FIG. 105.—Painted trillium.

of much smaller parts, the stamens. Each stamen consists of a stalk or filament bearing an enlarged part called the anther. Each anther consists of four sacs which fuse into two as the contents become mature (Fig. 108, *C*). These sacs contain a quantity of yellowish spores which are the pollen grains. In the center of the flower is the stout, angular pistil which terminates in three long, slender, curved points (Fig. 108, *A*). On the inner surface of each of these

points is a roughened area that is sticky; these are the stigmas of the pistil. The base of the pistil contains a three-lobed chamber (Fig. 108, *B*), in which are many ovules.

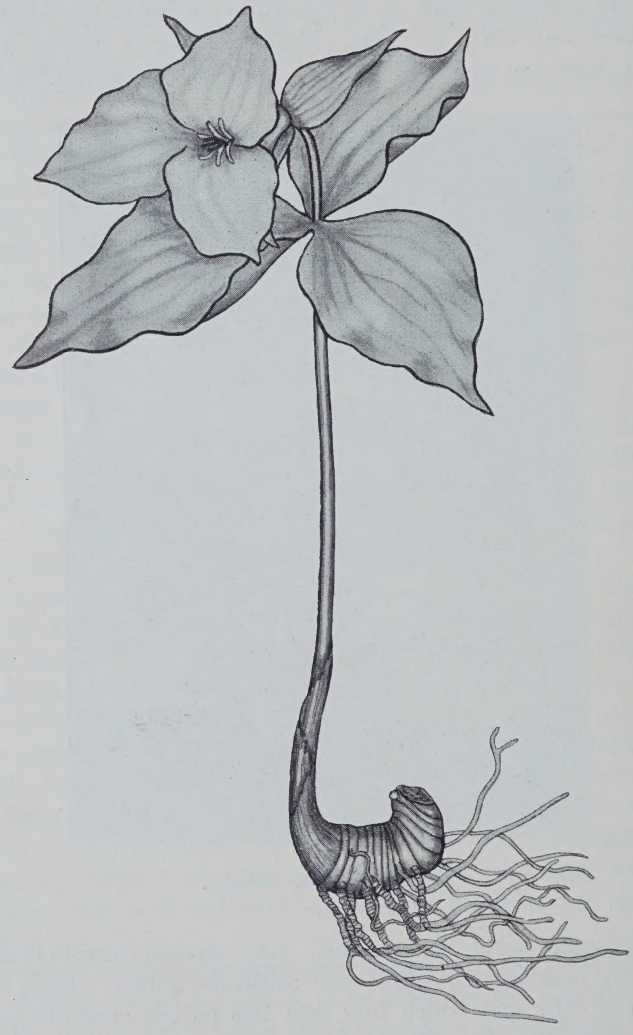

FIG. 106.—Trillium grandiflorum.

Study of the development of the stamens of flowers has shown that they are modified leaves; similarly, the pistil in trillium is composed of a group of three modified leaves called carpels.

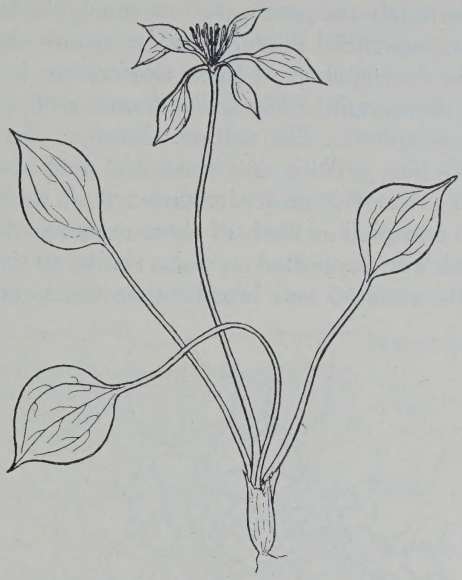

FIG. 107.—Trillium grandiflorum.

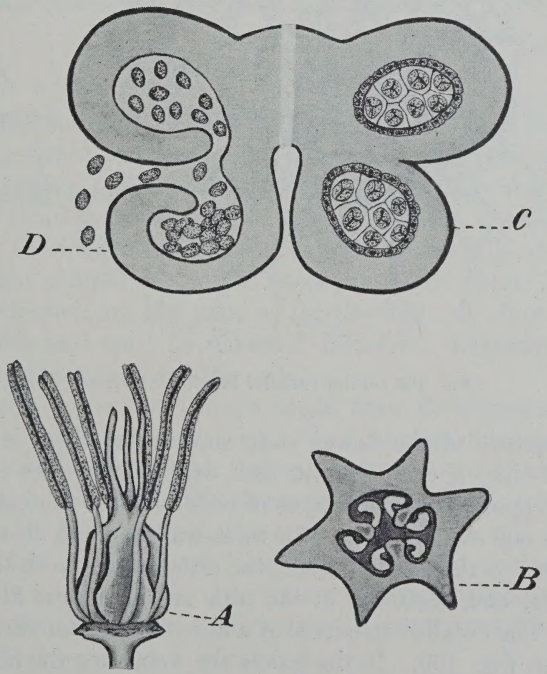

FIG. 108.—*A*, stamen and pistil of trillium; *B*, cross-section of the ovary, showing ovules; *C* and *D*, cross-section of anther; *C*, young anther, showing formation of pollen grains; *D*, mature anther.

In trillium the sepals and petals are very much like leaves, but one does not see the superficial resemblances as readily in the stamens and pistil. The development of these two organs, however, leaves no doubt as to their origin. The writer found striking confirmation of this theory in nature. The trillium shown in Fig. 107 showed basal leaves with long petioles, and sepals and petals both green and similar to the leaves. But most significant of all was the condition of the stamens and pistil. Each of these organs of the flower was green in color, all were supported on stalks similar to the leaf petioles, while some of the stamens were broader than the normal stamens.

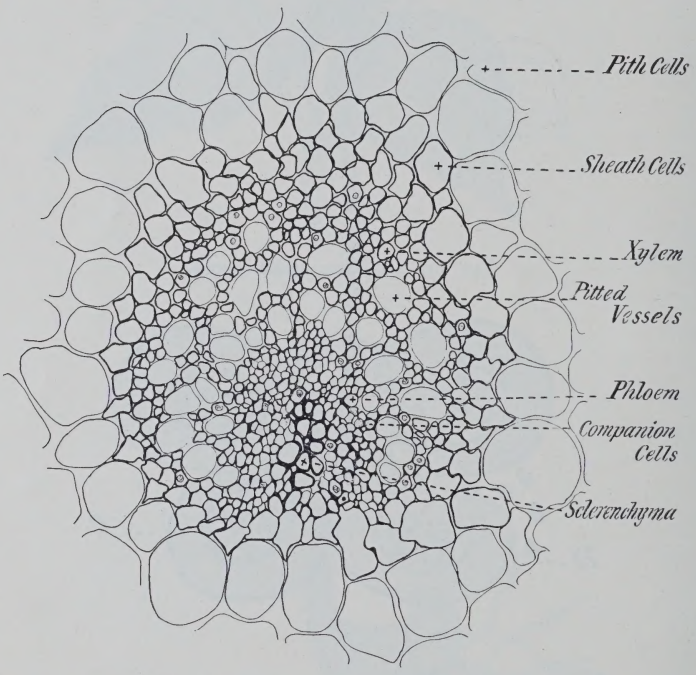

Fig. 109.—Fibrovascular bundle of trillium.

The structure of the flower stem shows that there is a definite number of tissues, each with its own work to do. On the outside there is an epidermis of one layer of cells which is protective; inside of this are one or two layers of a thick-walled tissue also protective in function. A thin-walled tissue, the pith, makes up the bulk of the whole stem, and scattered in the pith are numerous fibrovascular bundles. The detailed structure of a fibrovascular bundle in trillium is shown in Fig. 109. In the leaves the veins are the fibrovascular

bundles and the epidermis tissue becomes differentiated into an upper and a lower epidermis (Fig. 110). The under surface of the leaf is furnished with stomata which regulate the outgo of moisture from the leaf. The interior of the leaf is composed of cells which contain many chloroplasts. In the chlorophyll bodies the carbohydrate food of the plant is made (see page 132). While carbon forms nearly one-half of the dry weight of plants, yet all of this carbon is derived solely from the carbon dioxide in the air. It is estimated that a square meter of leaf surface can draw all of the carbon dioxide from 2500 liters of air in one hour. This furnishes sufficient carbon

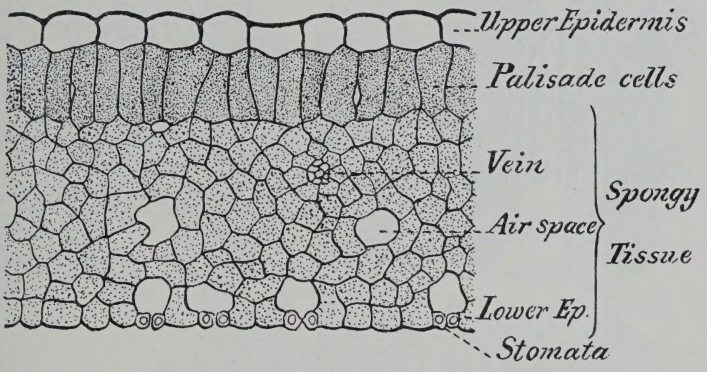

FIG. 110.—Section through lily leaf.

for the construction of one gram of starch. The food made in the leaf is transferred to all parts of the plant. The phloem cells in the fibrovascular bundle carry the food while the water travels in the xylem strands. All excess of food is stored in the underground stem. As the food circulates through the plant it is absorbed by the cells and utilized in the life processes of the plant. The principles of digestion are the same as for the frog. A plant protein is non-diffusible and must be rendered diffusible. Digestive enzymes prepare the plant food for the cells.

The young flowers of trillium begin their development in June or July and by autumn are well formed, though they remain protected by the sheathing bud during the winter and blossom in the early spring. The tips of the plants appear above the ground about the middle of April and the flowers are usually in full display by the first of May in central New York. Since the structures and processes concerned in the reproduction of flowering plants by seeds are essentially the same for all species, a general account of these structures and processes is given here.

The pollen grains are formed in the anther while the flower bud is still very small—in trillium at about the time that the shoots come above the ground. The pollen grains are single cells, usually with thick, roughened walls. They correspond to the microspores of the

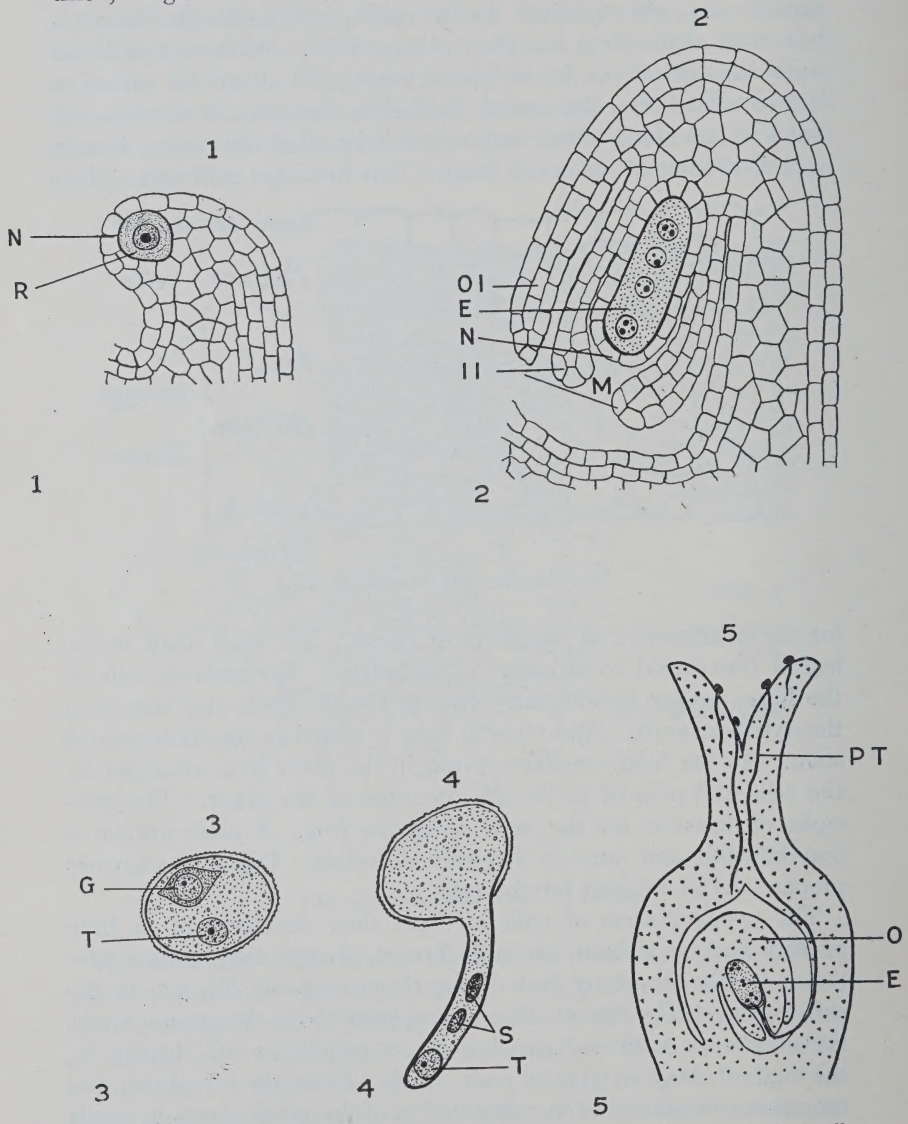

FIG. 111.—*1*, young ovule of *Lilium*. *N*, nucellus; *R*, embryo sac mother cell. *2*, older ovule; *E*, embryo sac; *II*, inner integument; *OI*, outer integument; *M*, micropyle. *3*, pollen grain of *Lilium; G*, generative cell; *T*, tube nucleus. *4*, growth of the pollen tube; *S*, sperm cells. *5*, diagram of pistil, showing the course of the pollen tube; *O*, ovule; *PT*, pollen tube.

pteridophytes. As the flower develops the nucleus of each pollen grain divides, forming two cells, known respectively as the generative cell and the pollen tube cell (Fig. 111, *3*); this is the condition of the pollen in the mature flower.

The ovule first appears as a projection on the inner wall of the ovary. Within the ovule is a large cell which may be called the embryo sac mother cell and is the equivalent of the megaspore of

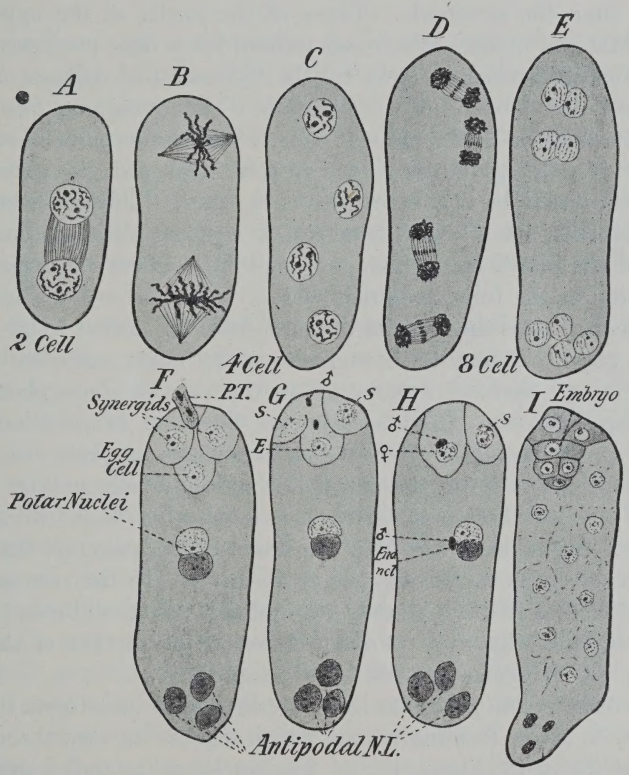

FIG. 112.—Development of the embryo sac of seed plants. *P.T.*, pollen tube. (Redrawn from Coulter.)

the pteridophyta. This cell is contained within the nucellus; as the ovule develops, two protective layers, the integuments, develop above the nucellus, but never entirely enclose it. The small opening that is left is the micropyle (Fig. 111, *1*, *2*).

As the flower grows the ovule enlarges and the nucleus of the embryo sac mother cell (Fig. 111, *R*) divides. The two daughter nuclei then divide simultaneously, producing four free nuclei (Fig. 112, *C*); another simultaneous division occurs, producing eight nuclei,

which collect in two groups of four each in the ends of the greatly enlarged embryo sac (Fig. 112, *D*, *E*). Delicate membranes occur about three of the nuclei at the end of the embryo sac toward the micropyle, forming a group of three naked cells known as the egg apparatus. The two lateral cells are the synergids; this term means "helpers," and indicates that they are supposed to assist in fertilization. The cell between the synergids is the egg; it is often somewhat larger than the synergids. Three of the nuclei at the opposite or antipodal end of the embryo sac remain for a time unchanged or in some instances organize cells by the formation of delicate walls; in any case they eventually degenerate. The remaining two nuclei, one at either end of the embryo sac, and known as polar nuclei (Fig. 112, *F*, *G*, *H*), move through the cytoplasm toward the center of the sac and come to lie in contact with each other. This entire structure of eight cells, one of which is an egg, is a sexual phase of the life history of the plant, the female gametophyte. It reaches this mature condition in the fully opened flower.

Pollenization is the transfer of pollen from the anther to the stigma of the pistil. It may be brought about by many agencies, such as wind, insects and even water, as in the case of some plants with submerged flowers. Of these agencies, the wind, is most important in the simple flowering plants, such as willows, poplars, etc.; but in the great majority of species pollenization is effected by insects which visit the flower to secure nectar or other food furnished by flowers. In securing this food the insect brushes against the anther and some of the pollen adheres to its body. In the course of the normal feeding of these insects some of this pollen will come in contact with the stigma of the same flower or of another of the same species and pollenization will be accomplished.

When the pollen grain has been transferred to the stigma it begins at once to grow, forming a tube which digests its way through the style of the pistil (Fig. 111, *5*). The nuclei of the pollen grain pass down into the tube and the generative cell soon divides into two sperm cells (Fig. 111, *4 S*). This structure of three cells is the other sexual phase of the life history, the male gametophyte. The tube continues its growth through the tissues of the pistil until it reaches the vicinity of the ovule, where it turns aside and enters the micropyle. A passage is digested through the nucellus and the two sperm cells are discharged into the sac. One of these fuses at once with the egg cell (Fig. 112, *H*); this is fertilization, the sexual process involved in reproduction in seed plants, and is not to be confused with pollenization, which is not sexual.

The other sperm cell moves through the cytoplasm to the center of the sac, where it comes in contact with the two polar nuclei (Fig. 112, *H*). The three nuclei then fuse, forming the primary endosperm nucleus, and the process is called triple fusion. This nucleus soon divides and repeated divisions of the daughter nuclei follow, producing an extensive thin-walled tissue, the endosperm, which fills the entire embryo sac. This is a nutritive tissue and supplies food to the embryo.

The fertilized egg soon divides, forming a mass of several cells, the embryo (Fig. 112, *I*). The further growth of the embryo carries it deep into the endosperm, from which it absorbs food. At the same time the integuments about the embryo sac harden and become the seed coats or testa. The embryo now stops growing and remains in a dormant condition and the seed is mature. When the seed is placed in favorable conditions of heat and moisture, water is absorbed and the embryo resumes growth; this is the germination of the seed and results in the formation of a new plant.

It is to be noted that the life history of a seed plant shows the same alternation of sexual and sexless phases that is seen in the lower groups. The ordinary flowering plant of which the trillium is an example is the sexless or sporophyte phase, and the nucleus of each cell contains twelve chromosomes. This plant produces microspores, or pollen grains, and megaspores, or embryo sac mother cells; in the nuclear divisions which produce these cells, the chromosome number is reduced to half its original number, that is, six in the case of the trillium. The pollen grains produce one of the sexual phases of the life history, the male gametophyte which forms sperms; the embryo sac mother cell produces the other sexual phase, the female gametophyte which bears an egg. Fertilization occurs by the fusion of a sperm cell with the egg; thus the nucleus of the fertilized egg contains twelve chromosomes, six of which have been contributed by the sperm and six by the egg. This fertilized egg develops into the embryo of the seed, which, upon germination, becomes the mature sporophyte or sexless phase of the life history with its characteristic number of chromosomes.

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CHAPTER XIV.

SOME INTERMEDIATE TYPES AND HYDRA—AN ANIMAL MADE UP OF TISSUES ONLY.

Intermediate Types.—In all of the study of animals and plants no one has ever observed one of them coming into being except through the direct influence of a previous living animal or plant. This is now regarded as the biogenetic law (page 160). Whatever may have been the primal origin of life the present animals and plants are genetically related. This fact makes it necessary to explain the possible origin of organisms consisting of more than one cell or the multicellular forms of life.

This problem is not fully solved, but a fair start has been made through the study of intermediate types which serve as an introduction to Hydra, an animal made up of tissues.

There are no sharp limits to the several phyla, so that there are a number of animals that fall between certain phyla or are grouped in an appendix to a given phylum. Some of these intermediate forms are interesting because they show how a higher form may have come into existence. This becomes a problem of great interest when the transition between *protozoa* and the next higher form, the many-celled *metazoa,* is made. In the unicellular animals the whole life is carried on within the limits of a single cell. Differentiation of work or structure is lacking, for the whole cell participates in the digestion of food, in metabolism and in reproduction.

The *Colonial vorticellidæ* consist of a number of like individuals arranged in a tree-like fashion (Fig. 83). Each individual is independent in all vegetative and reproductive functions. The cells are similar in size. These animals are termed colonial protozoa, but there is the beginning of cohesion of the cells.

Gonium is a sixteen-cell organism in which the cells are all alike, but united into one common body. Each cell eats, breathes, reproduces, etc. The cells are held together by their own gelatinous secretion. During the reproductive period the cells separate and act like unicellular organisms. This organism shows the first step in the union of cells, although it is not permanent (Fig. 113).

In gonium the reproductive cells are all alike but in endorina two kinds of conjugating cells are produced at intervals, the megagametes and the microgametes. Each of these cells is set free in the water, the small cells swimming about until they come in contact with the large cells, into which they penetrate. These two cells constitute a zygote, from which develops a new endorina.

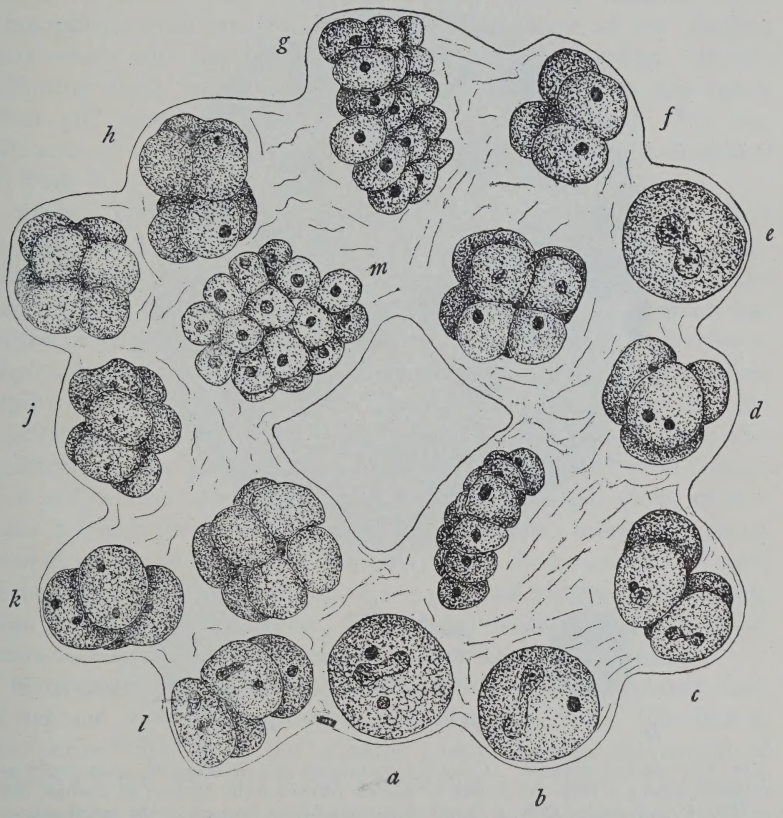

FIG. 113.—*Gonium pectorale* in reproduction. Each of the sixteen cells of the colony is dividing to form a daughter colony of sixteen cells. (After Calkins.)

Volvox is an organism consisting of a number of cells varying with the species from five hundred to fifteen thousand. The cells are arranged in the form of a hollow sphere and are separated from one another by a jelly-like substance through which pass fine protoplasmic threads. The cells are all much alike until the reproductive period, when certain cells become specialized into eggs or

sperms. During the growth of these reproductive cells they are nourished by the other cells in volvox, which is a marked step in advance over pandarina and endorina. Before one can recognize that there has really been a differentiation of cells the process must have been preceded by the formation of cells of different sizes.

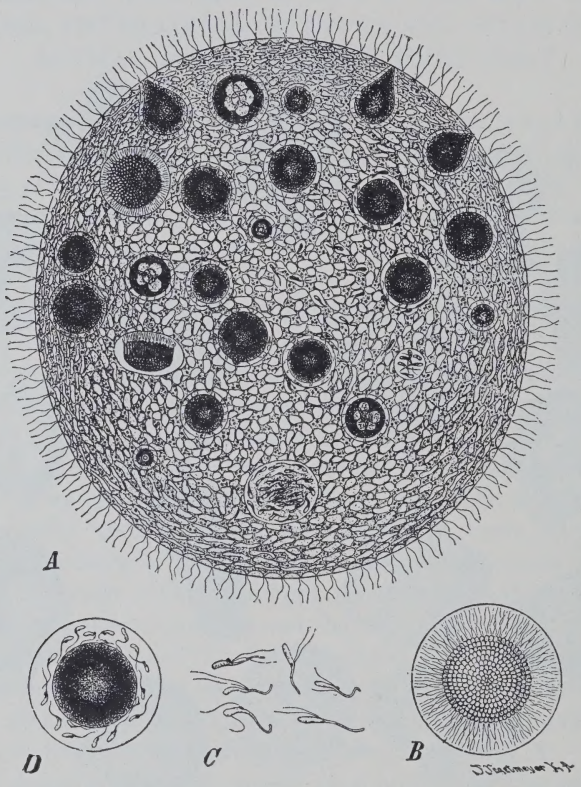

FIG. 114.—*Volvox globator*. *A*, colony containing various stages of development of ova and sperms (× 165); *B*, bundle of sperms formed from division of a single cell (× 530); *C*, sperms (× 530); *D*, egg cell surrounded by sperms in the mucilaginous membrane (× 250). (From F. Cohen.)

This means that unequal cell division is an accompaniment of differentiation. After the cells of volvox have produced and nourished germ cells until they can in turn produce new volvoxes they die.

In these examples given, and many more might be included, there is an obvious transition from the simple to the complex state. The cells tend to become more divergent in structure with an accom-

panying unification. "For efficient advance in the life scale integration and differentiation must go hand in hand." The higher animals are those in which integration and differentiation have been carried the furthest.

These intermediate organisms reveal two important biological principles, *the first steps in the physiological division of labor* and *sex dimorphism.* The first has already become familiar. Sex dimorphism considers the origin and significance of sex, dealing particularly with the distinction between ovum and sperm. In the following study of hydra the complete differentiation has taken place and sexual reproduction has become established. The significance of sex dimorphism in heredity and variation is described in Part V.

Kinds.—There are two common species of hydra that are abundant in fresh-water streams and ponds. Due to the presence of innumerable chloroplastic corpuscles one is bright green, which gives it the name *Hydra viridis.* The other species is of a light brown color, due to the presence of yellowish corpuscles, and is known as *Hydra fusca. Hydra fusca* is much larger, otherwise the two are very similar. Hydra can easily be seen in an aquarium jar attached to the side nearest the window. They vary in length from 2 to 20 mm.; this is largely due to the fact that the body is capable of great expansion and contraction. The hydra represents a small group of animals in which the absence of well-defined organs made up of tissues such as are found in the frog is a conspicuous characteristic. Nevertheless they are able to do all of the essential things that the frog does to maintain existence. They have been studied for many years as representing the simplest of the many-celled animals.

Morphology.—In general shape the body is a cylindrical sac attached at one end, which is the foot or basal disk (Fig. 115). The foot is not permanently fixed but adheres partly through the action of adhesive gland cells and partly by forming a vacuum. The mouth is somewhat star-shaped and is on the distal end, situated on the top of a conical elevation, the hypostome. Tentacles arise from the body at the junction of the body wall and hypostome and vary in number on *Hydra viridis* from four to twelve and on *Hydra fusca* from six to ten. They are capable of great expansion, as they move independently about searching for food and capturing it.

Food.—The hydra is more or less carnivorous, sometimes devouring algæ, etc., but feeding especially on the small water fleas which are seized by the tentacles and drawn into the mouth. The mouth

opens and the daphnid is slowly swallowed and passed into the digestive cavity. The indigestible parts are afterward expelled by way of the mouth. Within the body of the hydra there is a single cavity which communicates directly with the hollow tentacles. This cavity serves for digestion and circulatory work, and hence is termed the gastrovascular cavity or enteron.

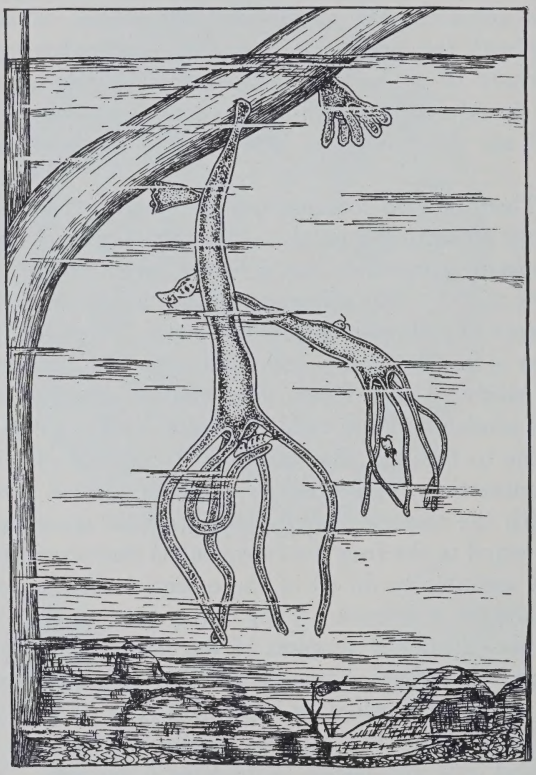

FIG. 115.—The brown hydra of Little Lake Clear, N. Y. During the summer this hydra becomes a bright red color. It feeds upon daphnia and cyclops as shown in figure. The small specimen attached to the leaf is in the contracted condition. Note the two buds on the body of the large expanded hydra.

Recent experiments upon hydra furnish additional information about the detailed method of feeding. The capture of food is a more or less passive action as any small object presented to hydra is seized and carried to the mouth. Indifferent substances are dropped after a few seconds, although occasionally pieces of the white of an egg

and blotting paper are swallowed. The digestive fluids of hydra are alkaline and have no effect upon hydra itself. Marshall has seen one hydra completely ingested by another, in whose cavity it remained for more than twelve hours. It was returned again none the worse. A tentacle is frequently swallowed along with the food to which it is sticking, and remains in the cœlenteron for some hours, but comes out quite unaltered. One hydra even went so far as to engulf about half its own body, beginning at the foot, where a Daphnia had stuck.

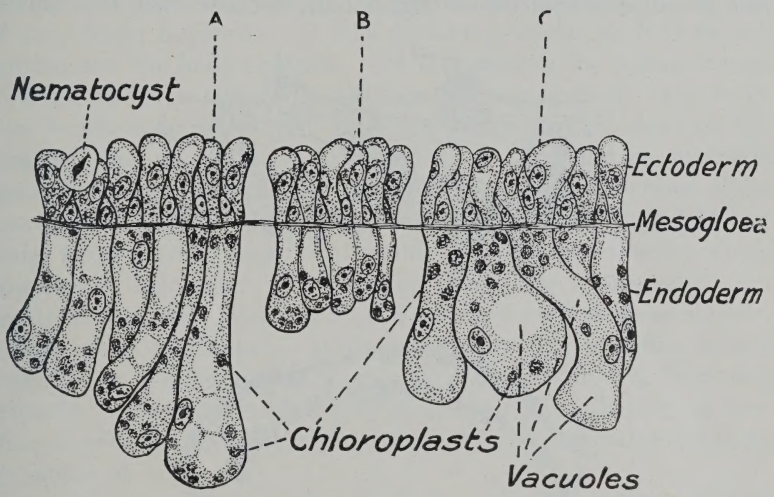

FIG. 116.—Section of the body wall of red-brown hydra taken from Little Lake Clear, February, 1917. *A*, region of esophagus; *B*, middle body region; *C*, taken about 1 cm. above the region of the foot.

Structure.—The body of the hydra is composed of two layers of tissue: the outer, the ectoderm, and the inner, the endoderm (Fig. 116). These two layers are separated by a jelly-like, non-cellular layer, the mesoglœa, which appears as a line when viewed in a microscopic section. The ectoderm has no connection with the food cavity, so that these cells are nourished only as food is absorbed, first passing through the endoderm and mesoglœa. The outer layer of ectoderm serves to protect the hydra and also to act as a generalized sense organ. The protective cells in the ectoderm are the nematocysts, which are described below. There are no well-defined sense organs such as ears, eyes, etc., yet the hydra responds to different degrees of light, to jars, and touch. There are, however,

some specialized cells in the ectoderm which respond to stimuli and are in connection with an indefinite plexus-like layer of cells to which the name nervous system has recently been given. The endoderm cells are longer than the ectoderm and are of two kinds—glandular and digestive.

Nematocysts.—The whole body, and particularly the tentacles, is covered with small projections, from the surface of which are stiff hairs. Each hair is connected with a highly differentiated cell termed the nematocyst or stinging cell. The stiff hair on the surface is called a cnidocil or trigger hair, because when this hair is

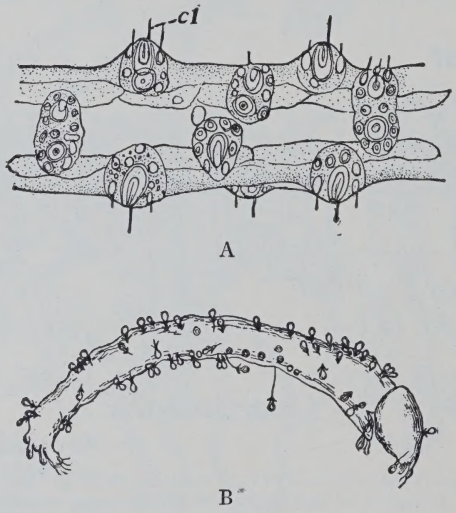

FIG. 117.—Nematocysts and their action: *A*, portion of a tentacle showing the batteries of nematocysts; *cl*, cnidocil; *B*, insect larva covered with nematocysts as a result of capture by hydra. (From Jennings.)

brought in contact with a water flea the effect is to cause the nematocyst to discharge a long thread, which penetrates the prey, causing paralysis. The fluid which is contained in the undischarged nematocysts is a poisonous secretion. When a stinging cell has been once discharged, the thread cannot be withdrawn, and so is useless to the hydra, and a new nematocyst must grow from the underlying cells to take its place (Fig. 117).

Locomotion.—Hydra when first introduced into an aquarium wander about more or less irregularly and slowly collect, not far from the surface of the water, on the side of the aquarium turned toward the window. Under normal conditions of light and food, the

hydra now become less active and may remain for some time with scarcely any change of position. As their food supply becomes exhausted, hydra begin to wander about in search of food, even floating about and sinking to the bottom of the aquarium to gorge themselves with organic sediment.

Careful observation of hydra as it moves about reveals that it usually employs a definite series of bodily movements. These Wagner describes as follows: "The body, expanded and with tentacle expanded, bends over to one side. As soon as the tentacles touch the bottom they attach themselves and contract. Now one of two things happens: (1) The foot may loosen its hold on the bottom and the body contract. In this manner the animal comes to stand on its tentacles with the foot pointing upward. The body now bends over again until the foot attaches itself close to the attached tentacles. These loosen in their turn and so hydra is again in its normal position. Trembley, in 1791, described these movements. (2) In the other case the foot is not detached but glides along the bottom until it stands close to the tentacles, which now loosen their hold. The result in either case is the same. By one such maneuver hydra travels a distance several times its own length when contracted. Hydra is further able to make slower journeys by gliding about on its own foot without aid from the tentacles. This movement is very slow, and noticeable only on very close observation. Nevertheless, hydra travels considerable distances by means of it."

Reproduction.—Reproduction in hydra may take place in two ways—the asexual and the sexual.

Asexual Method.—The asexual process consists of the formation of a new hydra without fertilization. The usual method is the growth of one or more buds, which first appear as slight bulges in the body wall. These gradually grow in length, small tentacles arise on the free end and a mouth appears. During all this time the gastrovascular cavity of the parent is connected with that in the bud. The rate of growth is largely determined by the amount of food which the parent hydra secures. After a time the bud becomes detached from the parent and leads an independent existence; it is like the parent in all particulars except size and possibly in the number of tentacles. There is also evidence to show that hydra may divide longitudinally as shown in Fig. 121.

Sexual Method.—The sexual method of reproduction takes place through the union of sperm and egg cells, during autumn and early

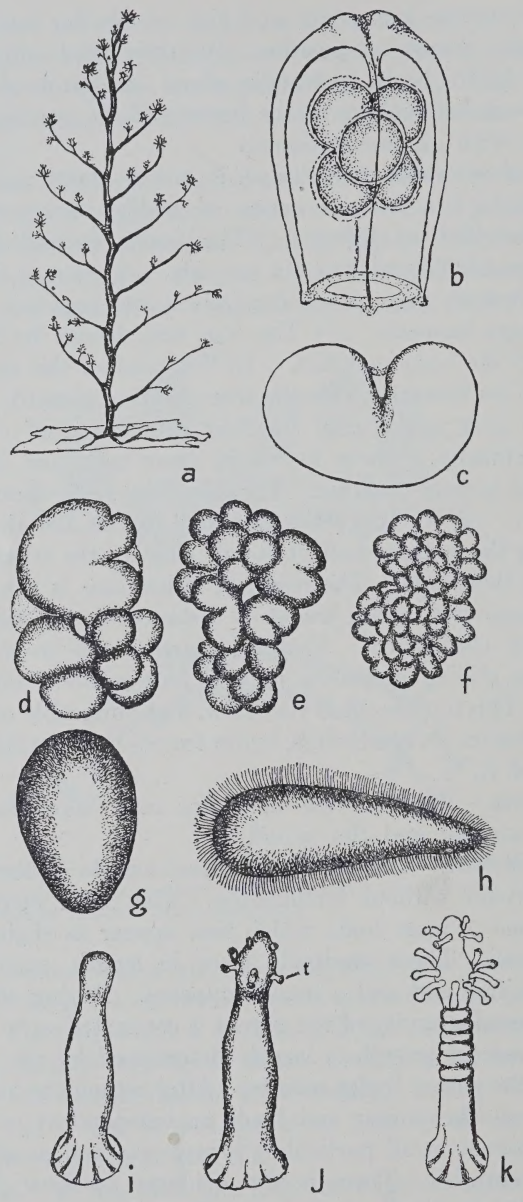

FIG. 118.—*a*, *Pennaria tiarella; b*, medusa with eggs; *c-f*, segmentation stages of embryo; *g-h*, the planula stage; *i-k*, the planula becoming a polyp. The medusa is grown asexually by the hydroid, *a*, while the medusa, *b*, grows either eggs or sperms. The fertilized egg in turn develops into a hydroid instead of a medusa. This method of reproduction is known as the alternation of generations and is illustrated in the stages *a* to *k*. (After C. W. Hargitt.)

FIG. 119.—Photomicrograph of hydra, showing eggs.

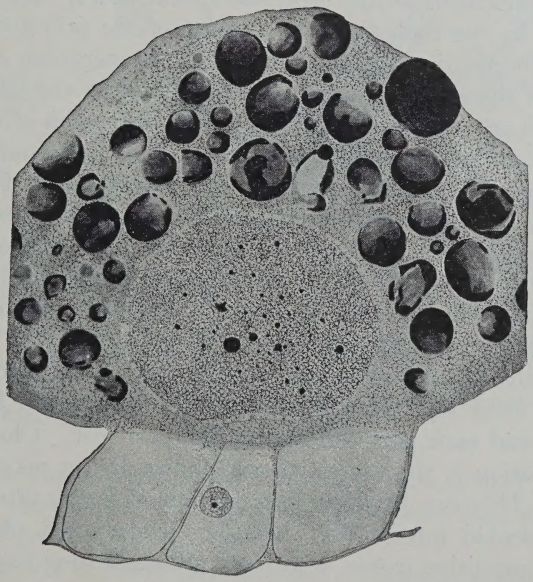

FIG. 120.—The egg of a hydra at about the time that it breaks through the ectoderm and previous to maturation. The nucleus at this time stains lightly, and the pseudo-cells, the remains of the young eggs that have been engulfed by this egg, appear as irregular dark bodies in the cytoplasm. (After Wager.)

summer. The animals are usually hermaphroditic. The sperm cells are found in small conical, whitish elevations a short distance below the tentacles. Testes may even develop in the ectoderm of the tentacles. When the sperm cells are set free in the water they continue active for two or three days. The egg begins to grow from one of the small ectoderm cells. There may be as many as four places where eggs are developing at the same time. When the egg is mature it undergoes maturation in a manner similar to that described for the frog's ovum, after which the egg is exposed by the breaking down of the outer ectoderm cells. Fertilization takes place as soon as a sperm cell penetrates the cytoplasm, usually within a couple of hours. Segmentation follows in a regular manner until the embryo is hatched. The time from the freeing of the eggs to the hatching varies with the season. During the summer, this may take place during three weeks. The embryo leaves the parent and remains inactive for some time before it becomes transformed into a hydra.

Egg Formation.—When the hydra forms an egg, the interstitial cells multiply and form a mass bulging out the ectoderm. In the nuclei, the chromatin collects around the periphery of the nucleus, leaving the nucleolus in the center of a clear space. The egg begins its growth by the coalescence of a group of the primitive ova; this process is frequently attended by nuclear degeneration. As the egg increases in size and becomes somewhat spherical, the edges become lobed. The egg continues to grow by the absorption of other interstitial cells and the protoplasm becomes filled with minute deeply staining dots. At a later stage the egg protoplasm is filled with a mass of degenerated cells and interstitial cell nuclei. (See Fig. 120.) These degenerating cells furnish energy for the embryo during its development. Remains of the cells can be traced into the young hydra and they do not entirely vanish until some time after hatching.

Regeneration.—Closely associated with the origin of a new hydra, especially by the asexual process, is the power of regrowing parts that have been lost through mutilation. Hydra can be cut into two parts and each part will regrow the part lost. Closely related to regeneration is the ease with which two hydra may be grafted together. This can be done in a variety of ways, often resulting in many-headed forms (Fig. 121 *E*). These cells of the hydra retain the primitive power of growth, although they have taken up definite positions in the organism, and their usual work is not that of reproduction. Closely related to this power of regeneration is that of regrowing the entire animal from isolated cells or clusters

of cells. In some of the simple sponges and hydroids Wilson has been able to regrow the entire animal from chopped pieces that were strained through cheesecloth (Fig. 123). Such experiments clearly indicate that the body cells have the power to regrow a new individual, which is a power that is usually confined to germ cells. These experiments in grafting and regeneration in the hydroids were the beginning of the study of grafting and the study of living

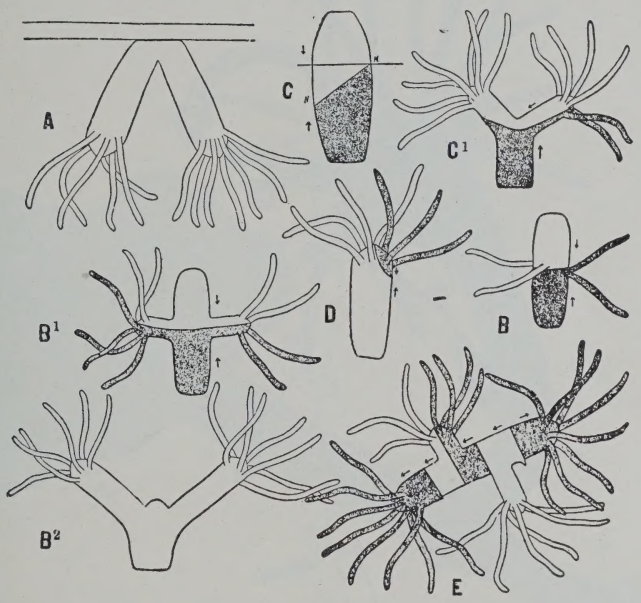

FIG. 121.—*A*, hydra split in two, hanging vertically downward; later, the halves separated completely; *B*, two posterior ends united by oral surfaces; B^1, same, it regenerated two heads, each composed of parts of both pieces; B^2, absorption of one piece leading to a later separation of halves; *C*, two posterior ends united by oblique surfaces; later, one piece partially cut off, as indicated by line; C^1, later still, two heads developed; *D*, similar experiment in which only one head developed; *E*, five pieces united as shown by arrows; four heads regenerated, one being composed of parts of two pieces. (King.)

isolated cells which, while yet in its infancy as a branch of investigation, has yielded an extensive number of facts that are rapidly becoming of great service to man.

Physiology.—It is interesting to compare the functional activities of hydra with the highly organized frog and the simple paramecium. When the hydra is hungry it goes through characteristic movements even when brought in contact with a piece of filter paper soaked in

beef juice. The several movements of the tentacles and the distal part of the body associated in carrying such a piece of filter paper into the mouth are called the food reactions. When a passing cyclops or cypris touches one of the tentacles it is shot full of nematocysts, which paralyze it. The tentacle that is held by its nettling threads to the animal bends and carries the food to the mouth. In this process the other tentacles often assist. As the prey touches the edges of the mouth it is passively swallowed.

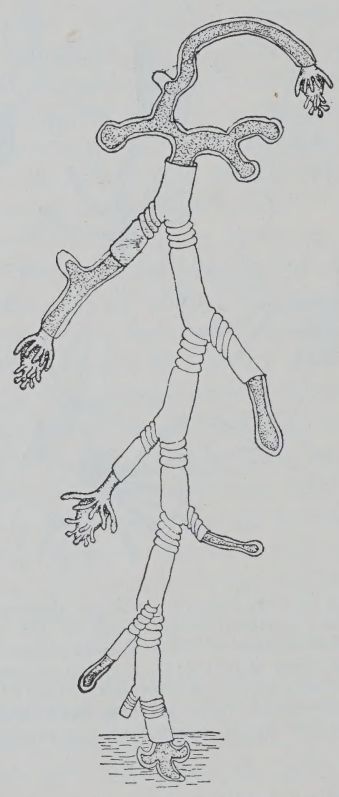

FIG. 122.—*Pennaria* anchored to the bottom of the dish by the distal end, showing regeneration. Unshaded portion is the old stem. (G. T. Hargitt.)

The gland cells in the endoderm now become active and those nearest the mouth pour out a slime which seems to act like the protein-dissolving ferments in the frog. We judge that there are no carbohydrate enzymes present in hydra, since starch grains when fed to hydra are ejected unchanged. The action of the slime enzyme

is to dissolve part of the food and to break up the rest into minute fragments. The dissolved food is absorbed into the cells and is distributed to the various parts of the body. It used to be customary to state that some of the endodermal cells could engulf small particles of food which were digested by the surrounding protoplasm. But the nature of the food, being chiefly minute crustaceans, makes it diffi-

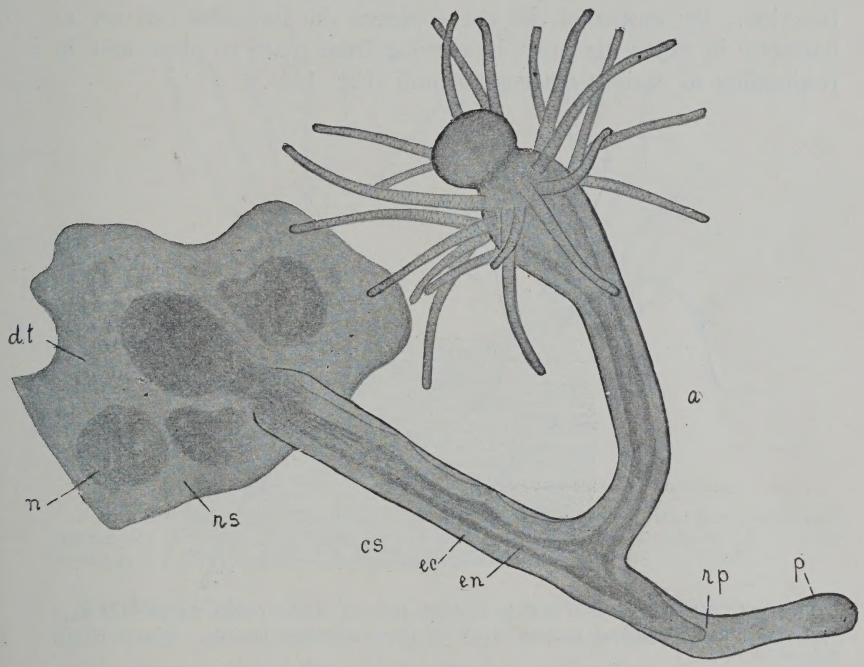

FIG. 123.—After the hydroid has been chopped into small pieces it is strained through gauze. The hydroid flesh streams through the pores of the gauze and falls into a dish as a fine sediment. This sediment consists of the cells of the body of the hydroid variously dissociated. This figure shows the amount of regeneration that took place in six days in *Eudendrium*. *n*, nodule of living tissue; *ns*, general mass; *cs*, outgrowth which has divided and produced, *a*, hydranth on one branch; *ec*, ectoderm; *en*, endoderm; *p*, perisarc of outgrowth; *rp*, regeneration point. (H. V. Wilson, in Journal of Experimental Zoölogy.)

cult to see how such a form of digestion could take place. Repeated observations, extending over many years, by Prof. C. W. Hargitt have failed to detect a single instance of the engulfing of particles of food by these endodermal cells. The undigested residue of the hydra's meal is defecated through the mouth.

There are no special cells that take charge of respiration and excretion in hydra, but as the whole animal is immersed in the water,

oxygen is taken in by any of the cells from the water and waste substances are cast off into it. In the frog the skin and lungs absorb oxygen from the air, and the skin at times from the water. The skin and lungs cast off carbon dioxide and the kidneys nitrogenous wastes.

The fact that certain cells are specialized to form even a diffuse network of nerve cells indicates the beginning of differentiation of function. By means of the nerve plexus the tentacles can act in harmony in capturing prey, in moving from place to place and in responding to various external stimuli (Fig. 124).

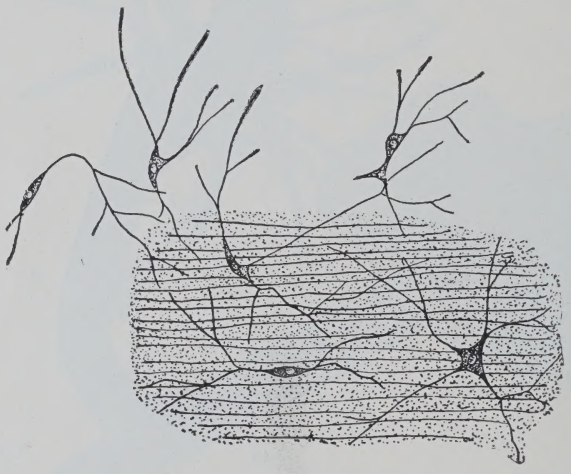

FIG. 124.—Plexus of nerve cells in the ectoderm of *Hydra fusca;* the parallel lines represent the longitudinal muscle fibers on the supporting lamella. (From K. C. Schneider.)

Nervous System.—Nerve cells are present, especially in the foot and the head and tentacles. These cells consist of (1) ganglion cells and (2) cells which are more or less intermediate in form between the ganglion cells and epithelial cells. These cells are of various shapes and give rise to several kinds of nerve processes. "The processes of one cell can often be seen to unite with those of another, so that the cell-body appears to lie in a network of interlacing threads. Many of the processes apparently end freely, sometimes in a small knob, while others are attached to the muscle fibers of myo-epithelial cells from which they cannot be detached by tapping on the cover-glass or by irrigation under it. The ganglion cells of the body are usually simpler and less branched than those of the head or foot."—Sheina Marshall.

The question has often been raised as to the power of an animal like the hydra to initiate movements from within its own body. Jennings has made a special study of this form of movement in hydra and believes that spontaneous movements can be observed. The body and tentacles may contract suddenly and then slowly expand. This is illustrated in Fig. 125.

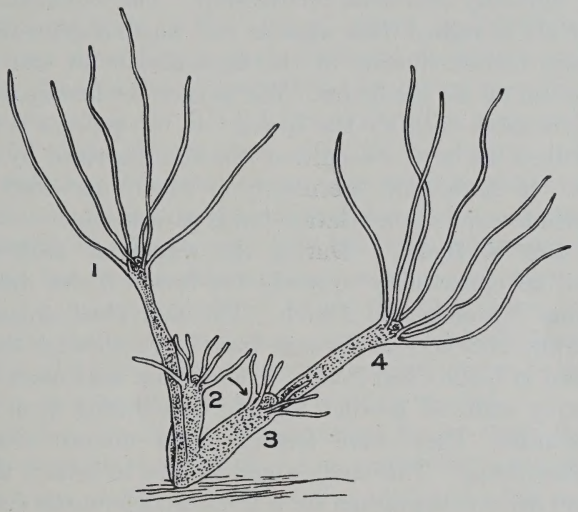

FIG. 125.—Spontaneous changes in an undisturbed hydra. Side view. Extended animal (*1*) contracts (*2*), bends to new position (*3*), and then extends (*4*). (After Jennings, "Behavior of the Lower Organisms," Columbia University Press.)

Symbiotic Cells.—The hydra exhibits another physiological habit that is not present in the frog. This is the peculiar relation that exists between the hydra and the greenish and yellowish chloroplastic corpuscles. These chloroplastic bodies are minute unicellular plants (Chorella vulgaris). They are found in large numbers in the bases of the endoderm cells. These bodies are passed on to the offspring through the egg cell or in budding. (Fig. 116.)

There have been many attempts to make a pure culture of the green organism living within the endoderm cells, but no one has succeeded in obtaining any large numbers. The question to be settled is what is the relation of these plant cells to the life of hydra? Whitney in 1914 was able to remove these green bodies from hydra by placing the specimens in a weak solution of glycerin (0.5 per cent) for a few weeks. During this period the endodermal cells swelled up and extruded the algæ which were then thrown out by the mouth. By this process he was able to secure several colorless hydra which

lived normally in the aquarium for some time without being reinfected. They retained all of the features typical of hydra except the color. Marshall placed hydra in glycerine and was not able to remove these green algæ. The endoderm appeared to be quite normal in size and the algæ were arranged as usual.

It appears from these recent studies that the algæ and the hydra live in a mutually beneficial relationship. The explanation, then, is that we are to regard these algæ as very much degenerated plants using waste carbon dioxide in the manufacture of starch. This waste is given off by the hydra. The oxygen set free in the starch-making process is used by the hydra. If the process is mutually beneficial then we have a condition which is described by the term symbiosis. If the benefits are mostly or wholly one-sided then the correct term to express the relationship is parasitism.

Winter Life of Hydra. — During the winter of 1916–1917 the writer had an opportunity to study the brown hydra during each month from November to March. The individual animals came into the State Hatchery at Saranac Inn, N. Y., through the in-take pipe located in Little Clear Pond. These hydra were observed to be in an active state of asexual reproduction during each of these winter months. They were feeding upon minute crustaceans, *Cyclops americanus*. This study would lead us to believe that these minute and delicate organisms are active throughout the entire year.

Before scientific students worked out the complete life cycle of the cœlenterate animals, it was supposed that jelly-fish and hydroids died after discharging their sexual products. Weismann formulated his theory of the origin of death upon this assumption. Some of the jelly-fish such as Fernaria and Obelia die within a few hours after discharging the egg or sperms, while Aurelia and Cyanea live for several weeks or months; but in each instance provision is made for the perpetuation of these animals by one phase of the life cycle that is able to continue during the winter. In the colonial hydroids, the extensively branching hydrocaulus breaks down after hibernating leaving the jelly-fish a mass of hydrorhiza that appear dead but are really in a state similar to hibernation in higher animals. In the spring these masses grow anew; the hydrocaulus and hydranths are ready for another active period. Just how many times this restive or hibernating period is assumed is not known. The writer's observations on hydra and the notes on hydroids by Prof. C. W. Hargitt indicate that the duration of life even in cœlenterata is longer than earlier students thought and some of them reveal seasonal adaptations that for many years were mistaken for death.

CHAPTER XV.

THE "WORM" GROUP—THE EARTHWORM AS A TYPE.

Modern students of the "worm" group are convinced that we have at least three distinct phyla while the classification given in the appendix arranges the representatives that were once simply called worms under phyla IV, V, VI, VII and IX. The three best known of the several kinds of worms are: (1) The flat-worms which usually have a broad leaf-like form and are represented by the common fresh-water planarians, the parasitic liver-flukes and tape-worms; (2) the thread-worms or round-worms with the body unsegmented and here are placed the fresh-water horse-hair worms, and others which are parasitic on many animals of which the hook-worm is the most famous; (3) the segmented worms having the body made up of a series of similar parts with the earthworm and leeches as the common examples. It is this last group which will be studied.

The phylum *annelida* is distinguished by its structural pattern. The unit of structure is a small ring or somite that contains structural parts that reappear in as many rings as are found in the entire worm. These somites are slightly modified in the anterior end but in the main are almost identical. Nowhere else in the animal kingdom does this primitive plan of organization appear so simply. The cœlome is large and gives the effect of one tube within another. There are two openings to the alimentary canal. These animals are often termed the true worms and are in turn divided into two main classes: (1) the bristle bearing worms or the earthworms of which there are more than 1500 different species; and (2) the worms without bristles but with suckers at each end of the body, the leeches. Earthworms live in the sea, in fresh water and on land; and, while they are the most purely terrestrial animals that we know, yet these purely land-dwellers have been derived from water inhabiting forms and probably in comparatively recent years.

External Morphology.—The body of the earthworm is long and cylindrical. When crawling it constantly keeps a given surface in contact with the ground; this surface is known as the ventral and the opposite the dorsal. The earthworm is said thus to possess dorsoventral differentiation. There is no well-defined head, trunk

or tail. The mouth is located on the anterior end, and internally there are structures which are usually confined to the head region, and so the earthworm is said to have anteroposterior differentiation, The most conspicuous external structural feature of the earthworm is the presence of successive rings varying in size. These rings are termed somites and are the external expression of important internal arrangements of the organs. Animals which have somites are said to exhibit metamerism. This tendency to have the same structure repeated must have taken a firm grip on all of the animals that have evolved from the worm stage, as evidence of this plan of structure is continually cropping out. Metamerism is found in all of the arthropods and vertebrates, including man. For this reason alone the earthworm should be studied, as it helps one to understand many otherwise strange structures, such as the segmental arrangement of the muscles in fishes and all vertebrate embryos. The vertebræ, the paired spinal nerves, and intercostal bloodvessels are good examples of metamerism in man.

Habits and Special Senses.—In this connection every student should read Darwin's *Earthworms and Vegetable Mould.* The earthworms are nocturnal in habit and seldom leave their burrows in the ground except during the breeding season. During the daytime they are to be found near the opening of the burrow, but as dry summer comes on they move deeper into it. Earthworms hibernate singly or in numbers below the frost line. They are able to recognize the difference between day and night, although they do not have eyes even in a rudimentary sense. There are a number of specialized nerve cells in the skin that are connected with the nervous system. Structurally these nerve cells are all much alike, yet the worm is able to recognize, day and night, certain smells, also jars, and is very sensitive to touch in the head region. The fundamental protoplasmic property of irritability is here concentrated in certain cells in the skin, but these have not become differentiated into the well-known eyes, ears, etc., of the higher animals, and yet the earthworm is able to act as if it had special sense organs. The earthworm has been studied a great deal because of its very simplicity in an attempt to understand just what is essential to a special sense. Here the physiological differentiation has preceded a structural differentiation. A similar case is found in the fact that we can detect the difference between hot, cold, pressure, touch and pain in our own skin, and neurologists are not able to find definite structural differences between the nerve processes that enable us to recognize

these several stimuli. On the other hand the well-defined eyes and ears enable all of the higher animals to have more accurate information with reference to their surroundings.

Organ Systems.—The organ systems of the earthworm are briefly given because most of the parts are easily worked out in the laboratory. The plan of the body is that of two telescopically disposed tubes, a larger one typifying the body wall and a smaller one the digestive tube. Between these two tubes there is a considerable space, the cœlomic cavity. The cœlomic cavity is partitioned by numerous dissepiments, thin sheets of connective tissue extending from the groove between the somites to the digestive canal.

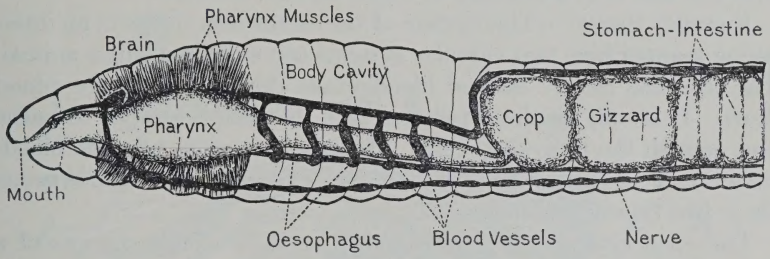

FIG. 126

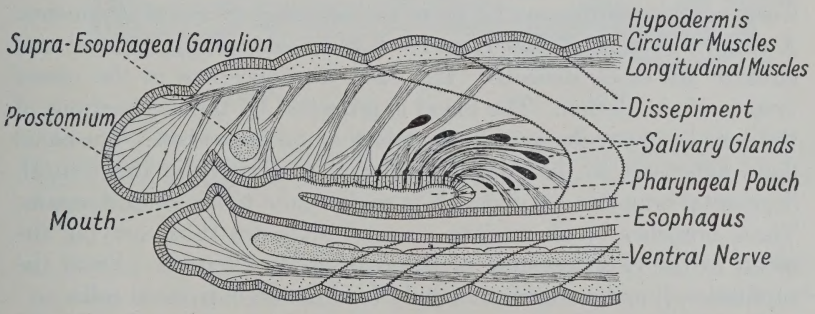

FIG. 127.—Diagram of the anterior end of the earthworm to show that the pharyngeal muscles are continuous with the longitudinal layer of the body wall and the position of the salivary glands.

Digestive Tube.—This closed tube extends the entire length of the animal. Definite regions are present that suggest the beginnings of specialized organs. The thin-walled mouth cavity continues into the pharynx which has its walls thickened by numerous fine muscles, Figs. 126. The salivary glands that open into a dorsal pharyngeal

pouch are concealed by these muscles, Fig. 127. A cross-section of this region shows two cavities.

The esophagus is an unmodified tube connecting pharynx and crop. Calciferous glands empty into it. While three pairs of these glands are commonly said to be present near its posterior end; there is really but a single pair that are lobed giving the effect of three distinct pairs.

The crop is a thin-walled distention of the digestive tube serving as a temporary store-house for the food; while the gizzard is thick-walled and used to grind the food (Fig. 126).

The remainder of the digestive tube is known as the stomach-intestine and it is specialized to digest and absorb food.

Vascular System.—This system of the earthworm shows in an interesting manner how two vascular systems can exist in a single animal. The frog has clearly defined bloodvessels through which the blood flows. It is only in the capillaries that the lymph escapes to bathe and nourish the individual cells. Hydra was seen to have no bloodvessels and the earthworm serves to show a possible transition between these two typical organisms.

The open type of circulation known as the cœlomic consists of a cœlomic fluid which is similar to the blood in composition and function. This fluid is forced back and forth by the movements of the earthworm and is continuous as there are openings in the dissepiments. A definite system of bloodvessels of which the dorsal, ventral and circular are easily dissected (Fig. 126), introduce one to the closed system of circulation. The blood is propelled by the contractions of the dorsal and circular vessels, the latter containing valves. The blood flows anteriorly in the dorsal vessel and posteriorly in the ventral. Segmental branches are given off in each somite to the several organs. These branches break up into minute capillaries thus carrying the blood in the closed system of bloodvessels to all parts. From the capillaries, lymph escapes to supply food in the individual cells.

Respiration.—The skin serves as the respiratory organ and the plasma of the blood carries the oxygen. Carbon dioxide escapes through the skin. This exchange of gases is aided by the secretion of mucous in the glands of the skin which keeps the outer layer of the body wall moist.

Excretion.—In addition to the skin, there is present a well-developed system of excretory tubules that are present in all but the first three or four segments. These excretory organs are known as nephridia (singular, nephridium). The two nephridia when present in a somite

lie below the digestive tube, one end passing through the body wall to open externally and the opposite end opening in the somite just anterior.

Each nephridium consists of five parts: (1) An enlarged funnel which is ciliated; (2) a narrow tube leading through the dissepiment; (3) the middle tube which is coiled; (4) the wide tube that is glandular; and (5) the short muscular tube that opens to the exterior. (Fig. 128.) Wastes are removed from the cœlomic fluid by the cilia on the funnel and by the cells in the middle and wide tube. Especial interest centers in these simple excretory tubules because the vertebrate kidneys seem to be composed of a union of similar structures.

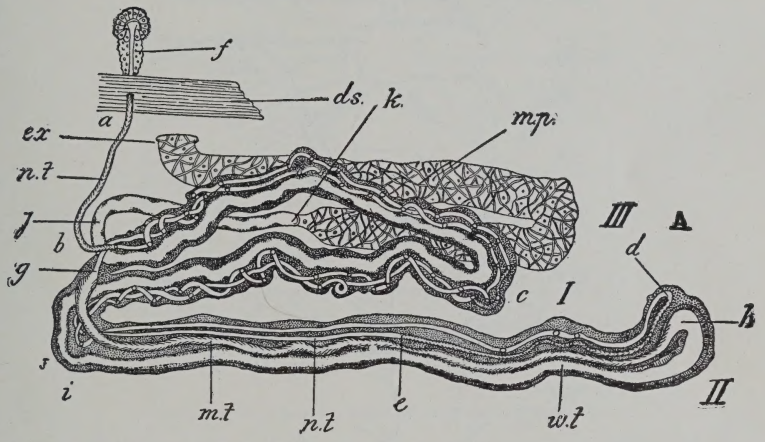

FIG. 128.—Diagram of the nephridium of lumbricus. *f*, funnel or nephrostome; *ds*, dissepiment; *n.t*, narrow tube ciliated between *a* and *b*; *m.t*, middle tube; *w.t*, wide tube; *m.p*, muscular part; *ex*, external opening; *I*, *II*, *III*, show the usual loops. (From Sedgwick and Wilson.)

Nervous System.—While the earthworm will always be studied because of its general simplicity of structure and the plan on which the body is built as it suggests that it may have been the forerunner of the more specialized organization of higher animals, the nervous system reveals a different type of biological problem.

There is present in all but the first three somites a single ganglion from which arise three pairs of nerves. These nerves show considerable variation in number, position and distribution. The anterior end of this ventral series of ganglia is known as the subesophageal ganglion. Two connectives pass from this ventral ganglion around the anterior end of the pharynx and enter the supraesophageal

ganglion sometimes known as the "brain" (Fig. 126). The nerves from the "brain" end in the prostomium. This leaves the first four somites to be supplied by the infraesophageal ganglion. Careful dissection will reveal that this ganglion and the connectives passing to the "brain" give off a variable number of nerves and that these nerves pass to these first four somites. One such dissection is shown in Fig. 129. If this is the correct interpretation then the anterior end of the nervous system has undergone some modification. The supra-esophageal ganglion has migrated posteriorly and the organs with which it was connected have largely disappeared except the prostomium.

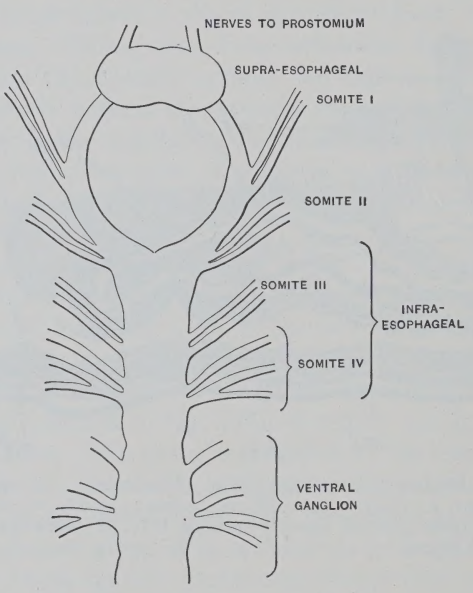

FIG. 129.—Drawing to show variation in the nerves at the anterior end of the ventral chain of ganglia. Three sets of branches arise from the subesophageal ganglion and these are distributed to the second, third and fourth somites. The two branches which arise from the connectives passed to the first somite. There were a few nerve cells in the connectives, just posterior to the origin of these nerves. (Drawn by Mary R. Crawford.)

Reproduction.—The earthworm has both male and female organs of reproduction, and because of this fact is designated as hermaphroditic. The ovaries are paired organs, minute and pear-shaped, and situated in the thirteenth somite. As the eggs mature they escape from the ovaries and drop into the funnel-shaped openings

of the oviducts, which lead to the exterior on the fourteenth somite. The four spermaries are minute flattened bodies in the tenth and eleventh somites. The immature sperm cells leave the spermaries and are retained in three seminal vesicles until mature. The sperms are carried to the outside through a pair of sperm ducts opening on the fifteenth somite. In the ninth and tenth somites there are two pairs of small flask-shaped bodies called seminal receptacles. These bodies have no structural connection with any of the other reproductive organs.

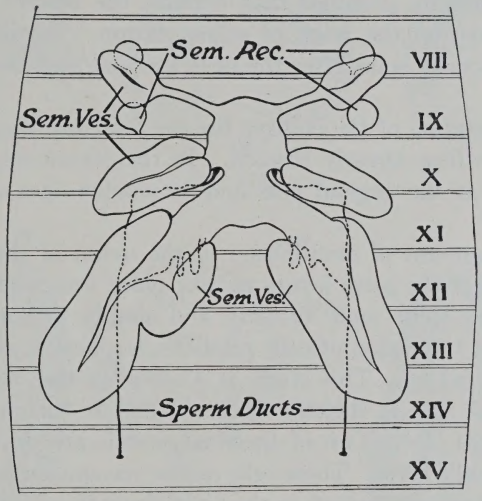

FIG. 130.—Diagram to show relation of male reproductive organs. *VIII–XV*, somite numbers. *Sem. Rec.*, seminal receptacles; *Sem. Ves.*, seminal vesicles.

Although the earthworm is hermaphroditic it is not self-fertilizing, for there must be an exchange of sperms. This is effected in copulation, when the seminal receptacles are filled with sperms from another animal. As the egg-laying period approaches the clitellum secretes a viscid mucus, which hardens and toughens on exposure to the air, thus forming a membrane. This membranous girdle is pushed forward, receiving eggs from the oviduct and sperm cells from the seminal receptacles. In this way the eggs are fertilized by sperms from another animal. Finally the capsule is pushed from the head end of the worm, each end contracting as it leaves the animal to form a cocoon. In this cocoon the embryos grow, feeding on the enclosed food and devouring each other until usually but one reaches maturity.

In general egg-laying is most usual during the spring and summer months but the egg capsules of the earthworm that lives in compost heaps where a relatively high temperature is maintained are found at all times of the year. The number of ova in these egg capsules varies with the species from a very few to as many as sixty but in every instance only a relatively few reach maturity. The smallest number of eggs is laid by the common earthworm, Lumbricus terrestris. In this species one only of the embryos reaches maturity.

Embryology.—The cytoplasm is laden with numerous clear yolk-spheres and minute granules that contain the reserve food-energy needed to carry on the work of segmentation. Fertilization takes place in the cocoon soon after the eggs are laid and cleavage begins at once.

The segmentation of the embryo for the first four stages is similar to that in the frog already studied. In the 16-cell stage, there are 4 larger cells at the vegetal pole and 12 smaller ones at the animal pole.

The large amount of deutoplasm in the ovum of the frog causes the formation of the germ layers to take place somewhat irregularly. These changes occur more directly and simply in the earthworm. The continued formation of cells produces a spherical cluster of cells containing a cavity. This stage is known as the *blastula.* (Fig. 131, *A.*) One side is slightly flattened and is occupied by larger cells. (Fig. 131, *B.*) Two of these large cells are destined to give rise to the middle layer. These cells can be recognized before the two main germ layers are formed as they withdraw from connection with the other cells and enter the cleavage cavity.

The embryo as a whole elongates by the rapid growth of cells and now consists of a two layered vesicle between which are lodged the cells that have been derived from the two mesodermal cells. (Fig. 132, *A.*) This elongation corresponds to the anterior-posterior axis of the adult worm (Fig. 132, *E*), consequently the large vegetal cells come to be surrounded by a layer of smaller cells, and the terms ectoderm and endoderm can now be applied. The endoderm surrounds a cavity with one opening. This cavity is the *archenteron* and the opening, the *blastophore.*

The blastophore is soon modified into a permanent mouth by lip-like thickening derived from the ectodermal cells. These cells are contractile and swallowing of the albumen begins in which the embryo floats. In this early stage the endoderm cells are thus shown to be digestive in nature. Eventually the ectoderm turns in at the

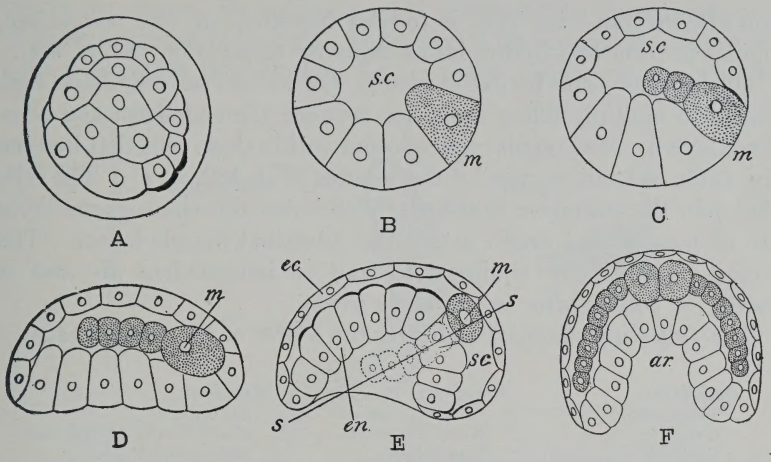

FIG. 131

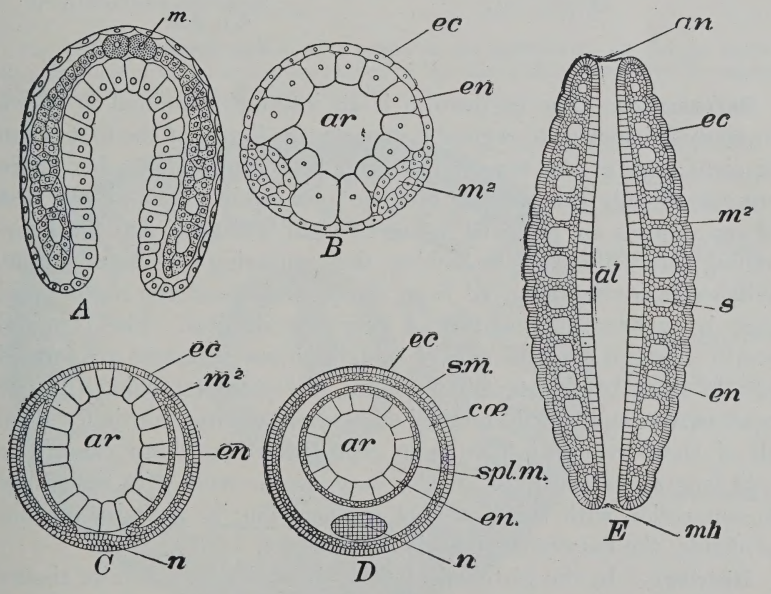

FIG. 132

FIGS. 131 and 132.—Diagrammatic figures of the early stages in development of the earthworm. *A–F*, gastrulation showing the formation of the two layers ectoderm, *ec*, and endoderm, *en*, and the beginning of the mesoderm, *m*, arising at the outset from the cells shown at *m;* the figures in 134 show the origin of the cœlomic chambers, *s*, and the dissepiments. *Ar*, archenteron, the primitive digestive canal; *al*, alimentary canal; *An*, anus; *mh*, mouth; *n*, nerve; *sc*, segmentation cavity. (From Sedgwick and Wilson.)

opposite end and the vent is formed transforming this simple sac, similar in form to a hydra, into a digestive canal (Fig. 132, *E*, *mh*).

During this same period of change the mesoderm cells have continued to multiply filling the space between the endoderm and ectoderm layers. Now regular spaces occur within these cells that become the adult cœlomic cavities of the somites (Fig. 132, *E*, *s*). The cells that join the primitive intestine and become the chlorogogue layer are of mesodermal origin as are the intestinal muscle layers. The young worm is now equipped to lead an independent life and it leaves the cocoon after two or three weeks.

The following summary indicates the source of the adult organs:

Endoderm	Ectoderm	Mesoderm
Esophagus	Outer epithelium	All muscles
Crop	Nervous system	Endothelium of cœlome
Gizzard	Stomodeum	Chlorogogue cells
Stomach-intestine	Proctodeum	Calciferous glands
	Outer ends of nephridia	Bloodvessels
		Nephridia, functional parts
		Seta sacs
		Reproductive organs.

Regeneration.—The earthworm is an interesting animal in which to study this power to regrow lost parts, for if any of the first seven or eight somites are removed all will be regrown, but when more are cut off only this definite number form again. Thus if the first fifteen somites are removed, seven or eight will grow and the intervening ones will always be lacking, thus rendering the animal sterile. When somites are removed from the posterior end the regenerated part is at first composed of a very few somites. The terminal somite contains the new anal opening and new segments are formed just in front of this terminal somite, the youngest being the one next to the end. This method of adding somites continues until all of those removed have been replaced. The worm cannot be split lengthwise and live. Hydra may also be studied to advantage in connection with this power of regeneration; or if hydra are not available, the flatworm, planaria, is excellent.

Histology.—In the histological analysis of the frog definite tissues were discovered as the several organs were studied. In a similar study of the earthworm definite tissues are found, each having its own position in the body (Fig. 133).

The following tissues are found in the earthworm: columnar, ciliated and pavement epithelium, muscular, nervous and blood, which can be easily studied. It is not easy to differentiate the

connective tissue. In a diagrammatic cross-section the arrangement of these tissues is indicated. The body of the earthworm is covered with a secretion that hardens into a tough membrane, the cuticle.

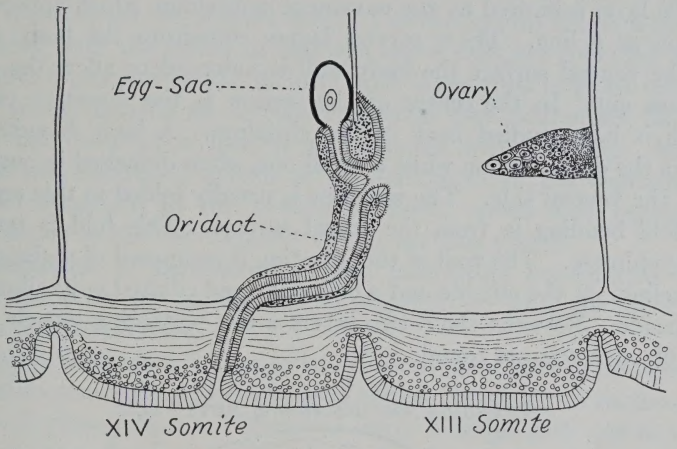

FIG. 133.—The female reproductive organs of the earthworm. As the ova mature they drop out of the ovary and are carried by the cilia of the oviduct into the egg-sac, where they are stored until after copulation.

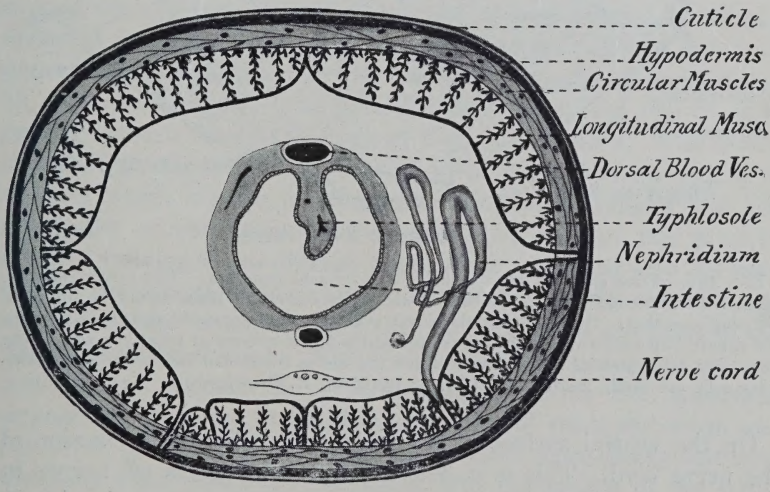

FIG. 134.—Diagrammatic cross-section of earthworm.

There are no cells in the cuticle, so that it cannot be termed a tissue. Immediately under the cuticle is a modified columnar epithelium containing special slime cells and sense cells in addition to the regu-

lar columnar cells. Next follows a circular and longitudinal layer of muscle. In the first the cells are cut lengthwise, while in the second they are cut crosswise. The inner end of the longitudinal muscle layer is limited by the pavement epithelium, which appears in section as a line. These several layers constitute the body wall. On the ventral surface the body wall is indented to allow the setæ to pass out. In the center of the section is the digestive canal, which is best studied back of the clitellum. A large bloodvessel marks the dorsal region while a small one, often detached in cutting, is on the ventral side. The intestine is usually folded in this region, the fold bending in from the dorsal surface. This fold is termed the typhlosole. The wall of the intestine is composed of a glandular epithelium on the outside and a columnar and ciliated epithelium on the inside. Between these two layers a few scattering muscle cells and bloodvessels are found.

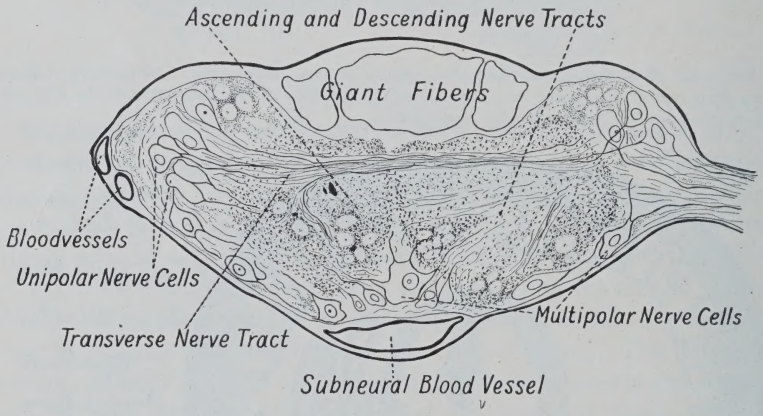

FIG. 135.—Diagram of a cross-section of a typical ganglion. The nerve cells are taken from three different sections and are more numerous than would be found in any single section. Observe that the nerve cells are on the outside and the ascending and descending pathways are in the center which is the reverse of what you saw in the frog. By using special neurological stains the nerve fibers can be shown and multipolar cells are easily made out. (Drawn by Mary R. Crawford.)

On the ventral surface of the body wall is found the section of the nerve cord. This is a double cord, which gives off nerves in each somite. Special stains are necessary to make out the details which are shown in Fig. 135. There are definite cells that send their processes out to the skin, where they receive the stimuli that have been transmitted by the peripheral skin sense cells. Other nerve cells send their processes to the muscles. A very few nerve

cells do not leave the nerve cord but connect the adjacent ganglia with each other. These are the association fibers. The same terms of afferent and efferent that were used in describing the frog's nerves can be applied here. The earthworm shows a marked advance over the hydra in that the nerve cells are collected into a definite organ and in that definite work is assigned to given neurons. The several ganglia are in communication with each other, but in a poor and incomplete fashion as compared with the frog. In this sense the earthworm stands as an illustration of the beginning of the development of the association fibers, which later become so important in the development of the nervous system.

Intelligence of Earthworms.—Some interesting experiments have been made on the earthworm to ascertain to what extent it can learn from experience.

Yerkes designed a T-shaped labyrinth of plate glass, with runways 2 centimeters wide, which was used to test the ability of earthworms (*Allolobophora fetida*) to "learn" to follow a simple path and to avoid an injurious chemical (or electrical) stimulus by reacting negatively to a peculiar tactile stimulus which regularly preceded the chemical. He had in mind these two questions: (1) Can the worm profit by experience; (2) can it "associate" the tactual stimulus with the chemical and acquire the habit of regularly responding to the sandpaper as though it anticipated the effect of the salt? From October 12, 1911, to April 30, 1912, a single worm was given 850 trials in passing through the labyrinth under various conditions. The results showed that the worm was capable of acquiring certain modes of reaction which involve a definite direction of movement and the association of two stimuli. He says: "In view of this positive result of training it was deemed worth while to proceed with the next step in the investigation—namely, amputation of the anterior segments, with the 'brain,' in order that the relation of the habit to the 'brain' might be studied. Forty hours after the operation it seemed desirable to resume the experimentation. With the apparatus arranged precisely as in the previous series of trials the worm was permitted to enter the T. It moved forward, more slowly and continuously than before the operation, into the middle of the stem. Having reached the common wall of the arms it turned to the left and five times pushed forward to the sandpaper, each time withdrawing upon contact. As it searched with the cut end for a way of escape, the 'tail' became active and moved about as if 'feeling' for a path. Shortly a turn toward the right was made and, with repeated attempts

to crawl up the glass wall, the worm approached the exit tube. The instant the 'head' end came in contact with the moist lining of the tube the worm pushed forward as in 'recognition' of the retreat (Fig. 136).

"The correct performance of a thoroughly ingrained habitual act of the kind studied in this investigation is not dependent upon the 'brain' (portions of the nervous system carried by the five anterior segments), since the worm reacts appropriately within a few hours after its removal. As the brain regenerates the worm exhibits increased initiative and its behavior becomes less automatic, more

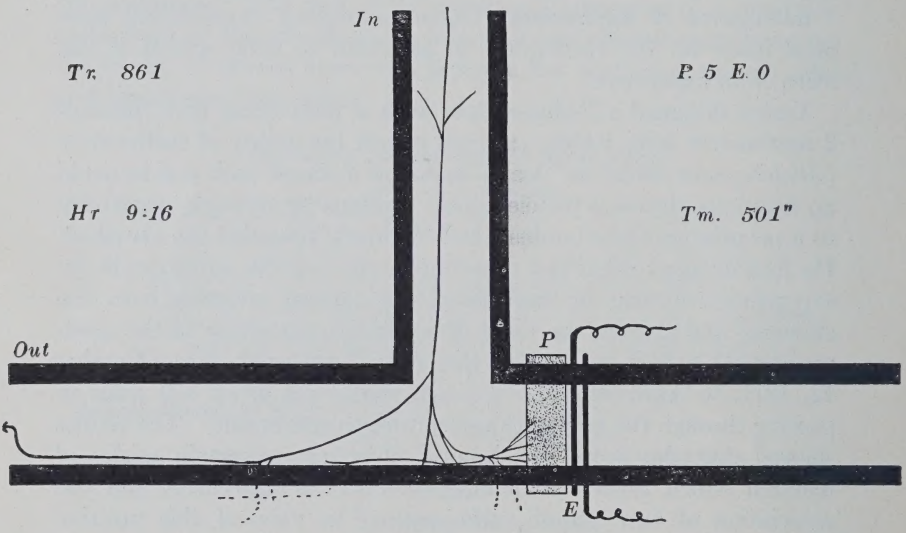

FIG. 136.—Diagram of T, showing path followed by earthworm in first trial after removal of the brain. *E*, pieces of copper wire serving as electrodes, insulated and kept at a fixed distance from one another by rubber; *P*, strips of sandpaper. (Yerkes.)

variable. Two months after the removal of the 'brain,' during the last four weeks of which period no training was given, the habits had completely disappeared. Systematic training of two weeks resulted in the partial reacquisition of the original direction habit. The various facts recorded in this investigation indicate that the removal and the regeneration of the first five segments resulted in the development of a worm strikingly different in behavior from the original worm."[1]

[1] Yerkes: The Intelligence of Earthworms, Jour. Animal Behavior, 1912, No. 5, vol. ii.

CHAPTER XVI.

MOLLUSCA.

General Characters.—The mollusca are known to have existed in the early Paleozoic epoch. The mere fact that this phylum was clearly defined at such an early date probably means that their origin and relation to the other invertebrate phyla is lost forever. In this phylum there are more than 60,000 living species.

The mollusca include soft-bodied animals, usually with an external shell; they are also characterized by a general absence of metamerism and by the cœlome being reduced to inconspicuous remnants around the heart and to the lumen of the gonads. The presence of a mantle which secretes the shell, a wide variety of relations between the foot and head (a head being absent in clams), and sexual reproduction constitute the characteristics which distinguish the clams, oysters, snails, octopi, etc., from all other animals.

The fact that clams and oysters are so generally used as food and so frequently cause disease is sufficient warrant for studying this aberrant group in a general course in biology. In this account only such structures are described as are necessary in understanding their method of feeding.

The calcareous shell of the clam consists of a right and left valve, held together by a hinge ligament. The valves are held in contact by adductor muscles, one anterior and one posterior. When these muscles relax the elasticity of the hinge ligament opens the shell. The shell grows in a regular manner so that one can easily tell which region is older. The oldest part of the shell is the small, conical knob, the umbone, just anterior to the hinge ligament. There are many concentric lines of growth on the surface of the shell, each of which marks a brief resting period. The youngest part of the shell is the outer margin. The ordinary clam on the market is from three to five years old, although there are fifty or more lines of growth.

When one valve is removed after cutting the adductor muscles, the inside of the shell appears as noticeably smooth and of a pearly luster. Muscle scars indicate where the muscles were attached. Along the hinge ligament margin various forms of interlocking teeth are found which keep the shell from slipping.

As one examines the soft body of the clam he finds the whole visceral mass covered by a thin membrane, the mantle. The mantle

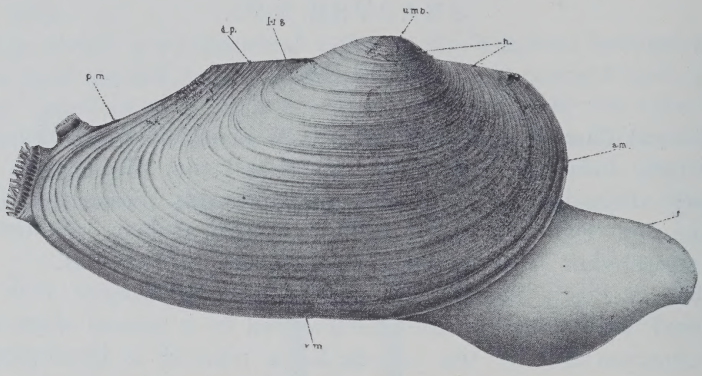

FIG. 137.—*Anodonta fluviatilis*. *a.m.*, anterior margin; *p.m.*, posterior margin; *d.p.*, dorsal margin; *v.m.*, ventral margin; *lig.*, hinge ligament; *f.*, foot extended; *umb.*, umbo; *h.*, hinge-line. Notice the position of the two siphons and the shape and size of the foot. (After Simpson.)

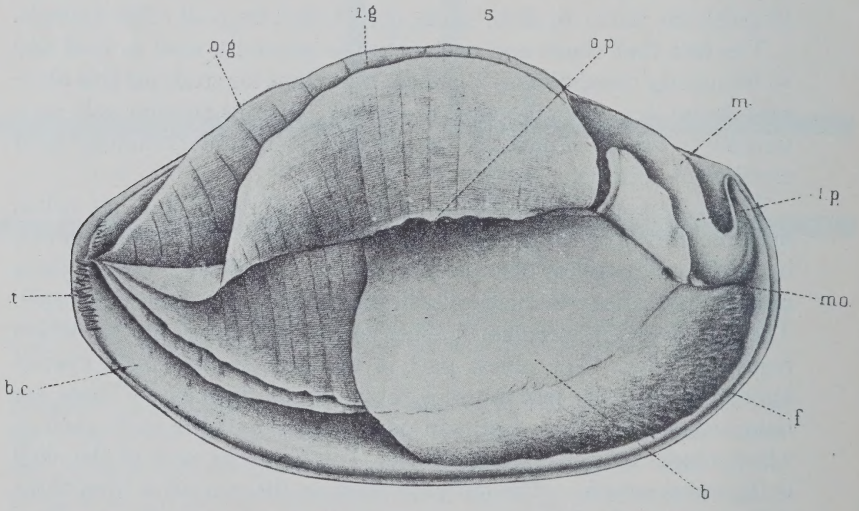

FIG. 138.—*Anodonta fluviatilis*, showing the mantle and gills thrown back, exposing the foot, body and labial palps. *f.*, foot; *b.*, body; *i.g.*, inner gill; *o.g.*, outer gill; *b.c.*, branchial cavity; *l.p.*, labial palpi; *m.*, mantle; *mo.*, mouth; *op.*, opening through the gills for the passage of the body; *t.*, tentacles of inhalent siphon. (After Simpson.)

is a structure peculiar to the molluscs. It has three general uses: (1) It secretes the shell; (2) it is the main organ of respiration;

(3) it removes foreign matter from the mantle chamber. The two folds of the mantle completely line the shell. On the posterior margin the mantle frequently becomes specialized into two tubes, the dorsal one serving for the escape of wastes while the ventral is the inlet into the mantle cavity for sea-water containing food. These two openings are the excurrent and incurrent siphons. There is a rhythmic movement of the mantle independent of the movements of the shell which is an important factor in setting up a respiratory current and removing waste material and foreign bodies from the mouth chamber.

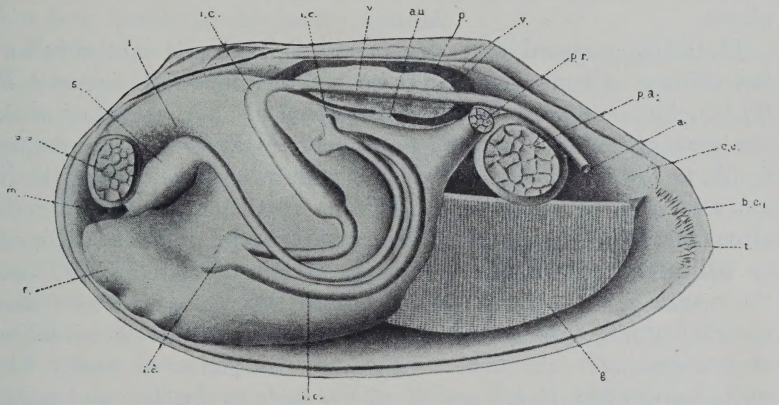

FIG. 139.—*Anodonta fluviatilis* dissected to show intestinal canal. *a.a.*, anterior adductor muscle; *au.*, auricle; *a.*, anus; *b.c.*, branchial chamber; *c.c.*, cloacal chamber; *f.*, foot; *g.*, gill; *i.c.*, intestinal canal; *l.*, liver; *m.*, mouth; *p.*, pericardium; *p.a.*, posterior adductor muscle; *p.r.*, posterior retractor muscle; *s.*, stomach; *v.*, ventricle. (After Simpson.)

The visceral mass of the clam consists of a large ventral muscular foot which merges dorsally into the several organ systems (Fig. 137). On each side of the visceral mass two pairs of gills are attached, their free edges hanging down in the mantle cavity.

Food of Clams and Oysters.—Clams and oysters are passive feeders and possess no organs for seizing food. The cilia on the gills cause a current of water to be drawn in through the incurrent siphon. The water strains into the interior of the gills and finally passes out through the excurrent siphon. As the water in the mantle cavity comes in contact with the mucous secretion on the surface of the gills all solid particles are caught. This mucous secretion is moved by cilia on the gills toward the mouth. On each side of the mouth

there is a pair of labial palps (Fig. 136), which are covered with cilia, and these assist the gill-cilia in moving and directing the food-laden mucus into the mouth. The entire digestive tube is lined with cilia which are probably solely responsible for keeping the food and mucus moving in the digestive canal.

The food of clams and oysters consists mostly of minute plants, diatoms usually predominating. Some authorities state that unicellular algæ, protozoa, eggs and various minute larvæ are eaten. The natural food of the edible clams and oysters lives in brackish water, especially at the mouths of rivers emptying into the sea. Long Island Sound and Chesapeake Bay are two such notable places.

The diseases caused by eating raw *shell-fish* occur in the following manner: Clams and oysters do not feed upon *B. coli* and *B. typhus*, for example, nor do these organisms live as parasites on the clam or oyster. In fact, these bacteria are not even adapted to life in the clam and oyster, for oysters when inoculated with *B. coli* and isolated do not give cultures of the inoculated bacteria after two weeks when kept at room temperature. This would seem to indicate that the disease-causing organisms were carried into the mantle cavity, where they are left by the water, and here they remain until they die. Oysters and clams must become reinfected at frequent intervals to be continuously dangerous as food. The relationship which *B. coli* and *B. typhus* have to the clam and oyster is a purely mechanical one. Clams and oysters will purify themselves in the course of two days if transferred to pure sea-water. Recent experiments indicate that oysters can be cleansed in six hours if the water is first treated with chlorine.

CHAPTER XVII.

THE CRAYFISH.

Kinds and Distribution.—Crayfish have been known to scientists ever since Aristotle wrote about the "Small Astaci Which Breed in Rivers." In the United States there are some seventy species of crayfish, most of which belong to the genus *Cambarus*, there being but five species of the genus *Astacus*.

Faxon says these two genera occupy distinct geographical areas. The genus *Astacus* is found in the old world in Europe and Western Asia as far as the Aral and Caspian Seas and in America in the region west of the Rocky Mountains in the streams draining into Great Salt Lake and the Pacific Ocean. It is thus seen to occupy the western sides of two continents. Cambarus is found in North America east of the Rocky Mountains in the region which is bounded on the north by Lake Winnipeg and New Brunswick and on the south by Guatemala and Cuba.

The crayfish are commonly found in streams and ponds, although one species lives in moist meadows in burrows. Economically the *Astaci* are valued as food by foreigners, and crayfish farms are maintained to supply this table delicacy. In the cotton belt, crayfish kill the young cotton plants by eating the tender roots.

Food.—While crayfish act as scavengers, eating various kinds of dead animals, they seem to prefer living animals, such as tadpoles small frogs, insect larvæ, etc. They also prey upon each other. During the daytime crayfish are inactive, but begin feeding at dusk and continue during the night.

General Characteristics. — Among the invertebrates the hydra, earthworm and crayfish are the animals best known to biological students. The reason for this nearly universal familiarity is that each exhibits important fundamental steps in the evolution of animals. The crayfish, in addition, is studied as a type of the most numerous phyla of the invertebrates, the *Arthropoda*, for here are classed according to some authorities more than six hundred thousand different species, all of which have three structural characteristics in common. These are the presence of modified somites, an exoskeleton and jointed appendages.

Modified Somites.—The body of the crayfish is divided into the anterior immovable region, the cephalothorax; and the posterior movable, the abdominal. The somites in the abdomen are all similar excepting the first and last. Each typical somite supports a pair of appendages. It is easy to recognize in the somites of the abdomen the simpler plan that exists in the earthworm. The question naturally arises as to how many somites have united to form the cephalothorax. Inasmuch as a typical somite supports a single pair of appendages, by counting the number of pairs of appendages in this region the problem is solved. Such an enumeration reveals that there are thirteen pairs, not counting the eye-stalk. This means that thirteen somites have united to form this cephalothorax region.

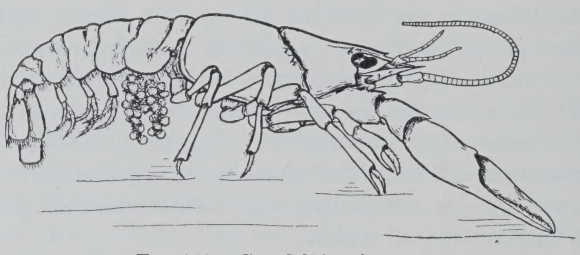

FIG. 140.—Crayfish bearing eggs.

In reaching this important conclusion one must have recourse to the facts of embryology which reveal the primitive and successive changes through which this region has passed. The cephalothorax of the crayfish not only shows how a general body region may have arisen as a modification of somites, but also how the head and thorax as distinct regions may have become differentiated, for there is a distinct groove in the carapace, the exoskeleton of this region, which marks off the head region from the thorax.

Exoskeleton.—The surface of the body is covered with a chitinous cuticle made hard by impregnated lime salts. This peculiar substance is composed of the following chemicals probably having this arrangement: $C_8H_{15}NO_6$. Wherever there is a joint this exoskeleton is thin and flexible, thus allowing movement. Such an external skeleton naturally limits the growth of the crayfish and prevents an increase in size. Yet common observation proves that young crayfish do grow larger. To allow this increase in size the whole of the exoskeleton is shed and the process is known as moulting or ecdysis. In moulting the old skeleton loosens and drops off

while the underlying cells secrete a new covering of chitin. Moulting also takes place in adult crayfish and the process necessitates that the lime be absorbed along the dorsal line of the head-thorax region and that the joints soften. The exoskeleton then splits along the line where the lime has been absorbed, the blood is withdrawn from the limbs and the whole anterior part of the body withdraws from the old shell. The abdominal region is drawn out last. The lining of the esophagus, the stomach and the hind intestine is also removed because they arise through an infolding of the skin. While some of these details do not apply to all Arthropoda, the main facts do.

Jointed Feet.—The scientific term, Arthropoda, describes this easily recognized characteristic. All members of this phylum have more than two pairs of jointed appendages, which in general move by hinge-joints. The appendages of the crayfish also furnish an interesting study in adaptation, as all of them can be shown to have the same general parts at first (Fig. 141).

Apparently the primitive form of appendage is the one found on most of the abdominal segments, called the swimmerets. Such an appendage (Fig. 141) consists of a simple basal protopodite supporting two flattened branches, the outer, an exopodite, an inner the endopodite. The last abdominal pair of appendages is enlarged, although no new structures are added. The same three primitive parts are readily distinguished (see uropod in Fig. 141). In a similar manner the several walking appendages are compared with the typical or primitive abdominal. In these there has occurred the loss of the exopodite and the distinct jointing of the endopodite. Sometimes the terminal joints are opposite and form pincers (Fig. 141). Anterior to the walking appendages occur six pairs that assist the crayfish in securing, tearing and crushing its food. Fig. 141 shows the form and parts of one of the three maxillipeds and the mandible. In a similar way the two antennæ are compared with the same typical abdominal appendage. Each of the antennæ has the endopodite greatly enlarged and double in the smaller one (Fig. 142). The only evidence of the exopodite in these two appendages is the large scale at the base of the large antennæ. It is expected that this general description of the similarities between the appendages will be supplemented by a detailed laboratory study.

A full comparison of the appendages of the crayfish necessitates a thorough knowledge of their embryology. In this way one determines which parts have been lost and which retained. Fig. 140

shows the walking appendages of the lobster with both an endopodite and exopodite. A similar stage in the development of the crayfish shows the same parts. While in the adult crayfish the several appendages have become adapted to swimming, walking, food-getting, feeling and tasting, yet a study of their development clearly indicates that each one is derived from the primitive abdominal type.

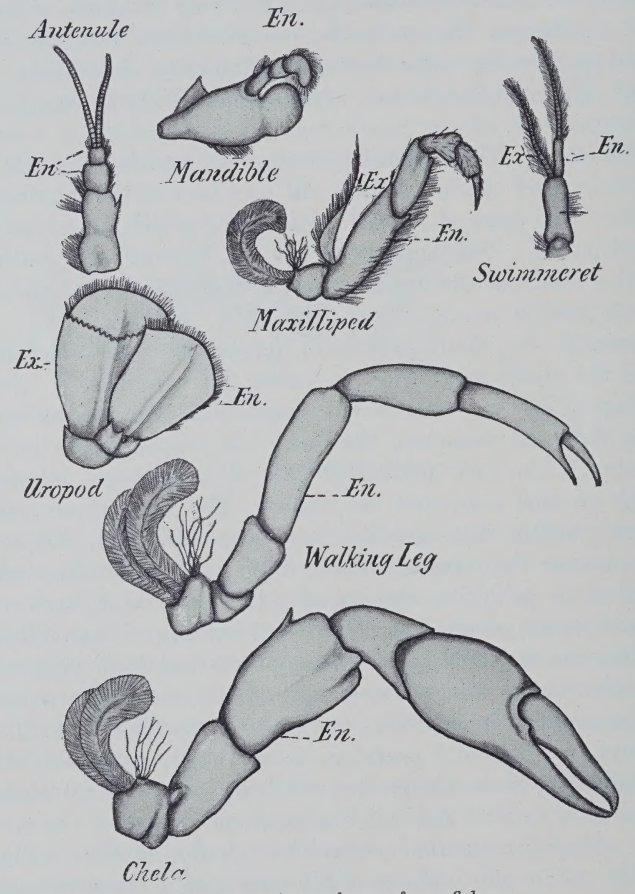

FIG. 141.—Appendages of crayfish.

In this comparison of the appendages of the crayfish in which highly specialized feet are shown to have parts in common with all the rest of the appendages, an important method of explaining many of the specializations in plants and animals is illustrated. Such structures as the appendages of the crayfish are termed *homologous organs*,

because they have had a common embryonic origin. The fact that in the adult stage these organs are widely divergent in appearance and use does not interfere with the more fundamental fact of the common embryonic origin. (For a further discussion see Homology, p. 301).

Organ Systems.—The several organ systems of the crayfish are all clearly defined, and in the nervous, reproductive and excretory systems are of a higher order than in the earthworm (Fig. 126).

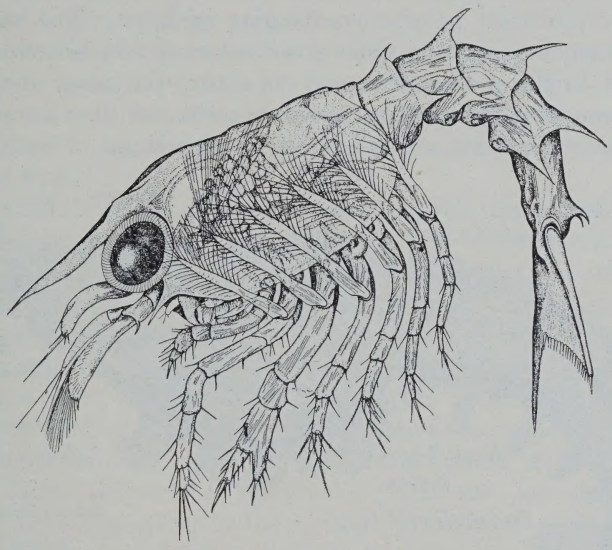

Fig. 142.—First larval stage of lobster, showing the biramus appendage in the thoracic region. The embryonic exopodite disappears.

The mouth is ventral in position and bounded by modified appendages. It opens into a short esophagus that expands into a capacious stomach. The stomach is divided into two regions by a constriction. The anterior is the larger and known as the cardiac stomach, while the small or posterior is the pyloric. A straight intestine extends from the pylorus to the anus located on the last abdominal somite and opening ventrally. In the cardiac stomach the chitinous lining is thickened in certain parts to form ossicles. These are arranged in such manner that the food is chewed by them. The several ossicles constitute the gastric mill.

On each side of the stomach is located a pair of digestive glands sometimes called the liver. Each gland consists of three lobes. The glandular epithelium lining the numerous tubules in each gland

secretes a digestive fluid that is very complex. The food of the crayfish consists of proteins, carbohydrates and fats, consequently it is not correct to designate this gland as a liver but rather as a pancreas. The digestive enzymes of this gland are probably the following: (1) A protease enzyme, which acts upon the proteins; (2) a lipase, the fat-emulsifying enzyme; (3) cytase, a cellulose-dissolving enzyme.

The crayfish breathes by means of gills contained in a narrow chamber protected by the overhanging carapace. The two rows of gills are named from their attachment as podobranchia when fastened to the protopodites and constitute the outer row. The second row is made up of the arthrobranchia, as they are attached to the articular chitin at the base of the appendages.

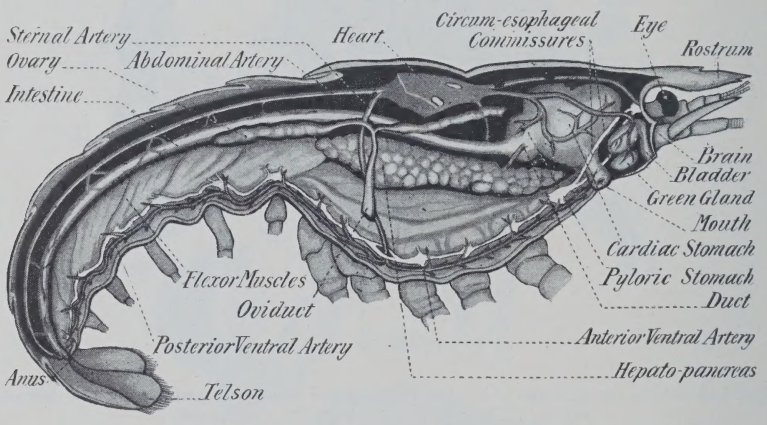

FIG. 143.—Median section of crayfish.

Each gill consists of numerous small filaments arising from a central axis. Two blood-vessels penetrate the base of each gill and give off a branch to each filament. The blood courses in through one and out through the other, during which process oxygen is taken from the water and waste carbon dioxide given off. The gill is an outpushing of the body wall, which is shown by the fact that it contains the same layers as the body wall.

The nephridia of each somite in the earthworm are limited in the crayfish to a single pair located in the anterior ventral part of the head. Each gland is divided into a glandular portion and a thin-walled bladder. The excretory duct opens on the ventral surface of the basal segment of the large antenna (Fig. 143).

The colorless blood-containing ameba-like blood corpuscles carry on the usual functions of the blood. There are well-defined arteries and a definite heart that beats rhythmically. Valves in each artery as they leave the heart prevent the blood from flowing back into the heart. After the blood is carried to the tissues it passes into irregular spaces termed sinuses. From the sinuses it is carried to the gills and from the gills to the pericardial sinus. The heart has several openings, the ostia, through which the blood enters the heart and is prevented by valves from escaping.

The muscles which enable the many joints in the appendages to bend in so many directions are numerous and arranged in pairs. Large muscles to flex the abdomen in swimming occupy nearly all of the space in the abdomen. These muscles are the chief source of food for man.

The crayfish, unlike the earthworm, normally contains the reproductive organs of but one sex. There is a single testis located beneath the pericardial sinus. It consists of two lobes on the anterior end and a single medial lobe posteriorly. From each side a coiled vas deferens passes to the protopodite of the fifth pair of walking appendages. The ovary is located similarly in the female and has a short, straight oviduct that opens in the protopodite of the third walking appendage. When crayfish copulate the male deposits sperms in a cavity on the ventral surface of the cephalothorax called the seminal receptacle. Here they are stored from October until egg-laying in the spring. Previous to egg-laying the female cleans the ventral surface of the abdomen and a slime is secreted by cement glands located in the abdominal appendages. This slime is spread over the swimmerets. The female then lies on her back and the one to six hundred eggs become attached to the hairs. Just how the sperms are distributed to the eggs is not known. The female keeps the eggs aërated and free from dirt. The eggs hatch in from five to eight weeks (Fig. 140).

The position and general morphology of the nervous system reminds one of the simple series of nerve ganglia in the earthworm. The series of ganglia in the abdomen are found in the six somites, regularly distributed. But this simple arrangement is not found in the cephalothorax, for the primitive somitic simplicity is lost in the fusion of two or more ganglia into single large nervous masses. This is particularly evident in the ganglia beneath and above the esophagus. Five thoracic ganglia can be recognized, but there are thirteen somites in the cephalothorax, so that the natural inference

is that the brain and subesophageal ganglia together represent these eight remaining primitive ganglia. This is on the assumption that

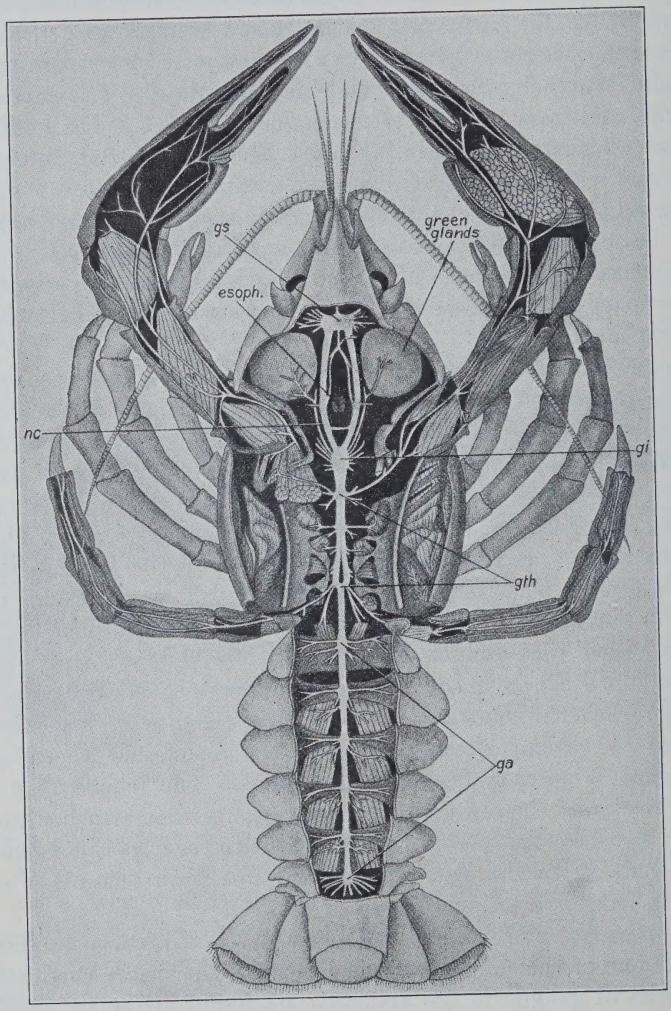

FIG. 144.—Nervous system of European crayfish. *esoph.*, esophagus; *ga*, abdominal ganglia; *gi*, infra-esophageal ganglion; *gs*, supra-esophageal ganglion; *gth*, thoracic ganglia; *nc*, nerve collar. (After Wilhelm Klein.)

each somite originally contained a single ganglion, for which there is a good deal of embryonic evidence. From each ganglion several pairs of nerves pass off, and from the brain and subesophageal ganglion

many branches. The eye, the antennæ and even the stomach receive nerves from the brain. The internal structure of the ganglia of the crayfish shows many more association nerve cells than are present in the earthworm, which is the real test as to which is the higher.

The crayfish shows a marked advance over the earthworm in the development of sense organs. Sense organs of touch, smell, taste, equilibrium and vision are all present. The entire body is sensitive to touch, especially the mouth parts and ventral surface of the abdomen. This sense is located in specialized hairs. Smell and taste are so closely allied that it is proper to designate them by the single term chemical sense. When meat juices are applied to the various parts of the body definite responses are made, and in some instances a series of movements follows which are well described as the feeding reflexes. The chemical sense is better developed in the mouth appendages than anywhere else. In the base of each small antenna is an open sac containing over 200 hairs. Each hair is supplied with a nerve. Small bits of sand are found in the sac. The whole structure was early called an auditory organ. Recent studies have failed to prove that the crayfish hears. When the ear sacs are removed or the ear nerves cut the crayfish swims in nearly any position, apparently just as well upside down as right side up. This suggests that these organs are for balancing or informing the crayfish when it is in its normal upright position. This is not an exclusive sense function of the crayfish, but is present in some jellyfish, snails and vertebrates.

The eye of the crayfish is on the end of a movable stalk. It is described as a compound eye because there are about 2500 distinct visual elements united in each eye. The external skeleton of chitin is transparent over the end of the eye-stalk, and for this reason is called the cornea. Fine lines divide the cornea into four-sided areas, called facets. Each facet corresponds to the individual visual element known as an omatidium. The compound eye produces an erect mosaic, as all of the rays of light that impinge on the pigment in each omatidium are absorbed. The only rays that are able to reach the sensitive part are those that pass directly through the center of the cornea because such rays reach the optic nerve. Each omatidium gives an incomplete picture of an object, but when the many partial pictures are united the whole object must appear as a mosaic. Such eyes are well adapted to detect movement in an object, as any change in position of a large object would be recorded in most of the 2500 omatidia.

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CHAPTER XVIII.

INSECTS.

Number.—If the estimate of over 400,000 as the number of the different species of insects is even approximately true, they form a class of animals more numerous than all the rest of the animal kingdom. While it is evident that one cannot hope to become acquainted with such a large number of separate species, it is, however, very easy to recognize an insect. Inasmuch as they have world-wide distribution and play such an important role in the life of man, it is desirable to know a few general facts about them.

General Characters.—One of the most remarkable facts concerning this numerous class of animals is their marked similarity. There are three distinct regions easily recognized—head, thorax and abdomen. In general the head bears the organs of special sense, of prehension and of mastication; the thorax, the organs of locomotion; the abdomen, the organs of reproduction. Metamerism as shown for the crayfish is present, although so greatly modified that one must study the embryonic stages to be able to locate the segments in the head region which consists of at least five primitive segments, while three are present in the thorax and eleven in the abdomen. There is an exoskeleton of chitin as in crayfish, although it is more flexible. Insects when first hatched frequently do not resemble the adult until they have passed through a change known as metamorphosis.

THE HONEY BEE.[1]

The honey bee is suggested as the form to be studied in the laboratory. But for those who prefer the grasshopper, the text of the bee will serve for comparison.

There are nineteen general orders (see page 374) of insects, and the one regarded as the highest, the Hymenoptera, is the one to which bees, wasps, ants and ichneumon-flies belong. Many students of animals regard the body of these insects as being more highly

[1] Students are urged to read "The Life of the Bee," by Maeterlinck in connection with their study.

specialized than the body of the frog, bird or even man. This is particularly true of the ant.

Kinds.—There is but one species of the honey bee, *Apis mellifica*, which is the same whether found in a hollow tree far from human habitation or in an apiary near a large city. Bees are not domesticated like the horse, but retain all of their natural instincts. The honey bee was introduced into the United States as early as 1638. Bee-keepers recognize several subspecies or races of the honey bee, such as "Italian," "German," "Caucasian," etc.

The Honey Bee Colony.—A colony of bees is the general expression used among bee-keepers, but in attempting to describe scientifically the social habits of animals the term colony is restricted to such

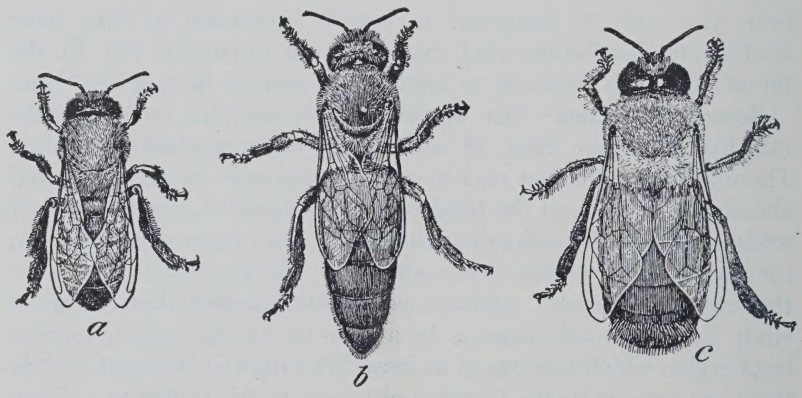

FIG. 145.—The honey bee: *a*, worker; *b*, queen; *c*, drone. Twice natural size. (Phillips, United States Department of Agriculture.)

groups of animals as have an actual structural union like the hydroids (Fig. 118, *a*). In place of the word colony, biologists employ the term community to describe the varied and interesting life of the higher insects: bees, wasps and ants (see page 330).

The bee colony consists of three individuals, a single queen, many drones and thousands of workers (Fig. 145).

The Queen.—The single queen in each colony is the largest of the three. Her contribution to the welfare of the colony is the laying of the eggs from which young queens, drones and workers develop. "The number of eggs laid by the queen varies from a few daily, in early spring and late fall in the northern regions, to about 1500 to 2000 a day at the height of the egg-laying season. Under special conditions, usually artificially produced by the bee-keeper, she may

lay as many as 4500 or 5000 eggs a day and maintain this rate for several days. *The weight of the maximum number that can be laid in a day is equal to about twice the weight of the queen at any time during the period, indicating a marvelous rapidity in metabolism.*" The life of the queen is three or four years in length, with a few cases on record of seven years.

Drones.—These are the male bees, and it seems strange that there should have developed a social organism with but one female and several hundred males, as is shown by the bees. The usual social unit of one male and one female thus becomes highly modified in the bee colony. Compare these relations with those that exist in the seal (page 332).

A single drone mates with the queen but once in the life of the queen. As a result of this act the drone dies. The remaining drones in the colony are heavy eaters and contribute nothing to the welfare of the colony unless the old queen dies and a virgin is hatched or introduced into the colony. In this case she must mate before she can lay eggs. When the food in the colony becomes scarce there is reason to believe that the drones are first starved and then removed from the hive by the workers.

Workers.—The workers are females with their sex organs undeveloped. "They are justly called worker bees. These bees feed the growing larvæ; clean, guard and ventilate the hive; build comb, gather nectar, pollen, water and propolis, and, in fact, do all the work of the hive, except that normally they lay no eggs."

The length of time that workers live varies with the season. During the active period of summer, six weeks is long enough for them to become old, and frayed-winged individuals are commonly seen dead outside of the hive. Workers hatched in the fall live until the spring brood of workers is ready to care for the colony.

Structure of the Honey Bee.—The bee is like a specialized crayfish in its general body plan. There are the same jointed appendages (Fig. 143), with the addition of wings; there is an exoskeleton hardened by chitin and a grouping of the somites into the three body regions, head, thorax and abdomen.

Internally similar organ systems are present, the details of which belong to laboratory study. However, three special features are presented because they are of great importance in understanding bees. These are their manner of respiration, of reproduction and the making of honey.

Respiration.—The method of respiration in the honey bee introduces us to a plan entirely distinct from the use of the gills of the crayfish or the lungs of the frog. In Fig. 146 is shown part of the tracheal air tubes and sacs in the body of the bee. These are connected with the surface of the body at definite places and the opening through the exoskeleton is called a spiracle. These spiracles admit fresh air and permit the contained air to escape through the action of the muscles of the body. The tracheal air tubes ramify throughout the body, even penetrating into the brain. By this means oxygen is carried to all of the cells of the body.

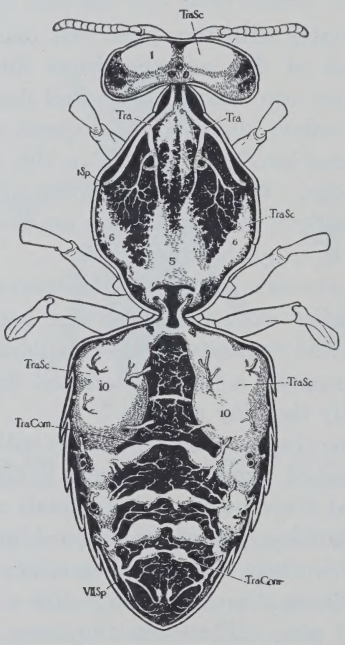

FIG. 146.—Tracheal system of worker, showing lateral and ventral parts as seen from above, with dorsal sacs and trunks removed in both thorax and abdomen. *Tra.* trachea; *TraSc*, tracheal sac; *TraCom*, tracheal commissure; *ISp*, first spiracle; *VII Sp*, seventh spiracle. (Snodgrass, United States Department of Agriculture.)

The tracheal system of air tubes in the bee is an illustration of the respiratory structures present in the body of all insects. Each order of insects exhibits modifications in the arrangement of the tracheal system, but the method of furnishing air to the cells is the same.

Reproduction.—The virgin queen takes her nuptial flight, during which she mates with a drone. In this act she receives spermatozoa which are stored in the sperm receptacle (Fig. 137, *Spm.*). The queen does not mate a second time, so that the sperms received constitute the only available supply during the entire egg-laying life of the queen, which is often four or five years. The sperms, then, remain alive in the sperm-receptacle of the queen, although they are "so highly specialized that they can take no nourishment." It has been estimated that a single queen may lay 1,500,000 eggs, which would require that an enormous number of sperms be received at mating.

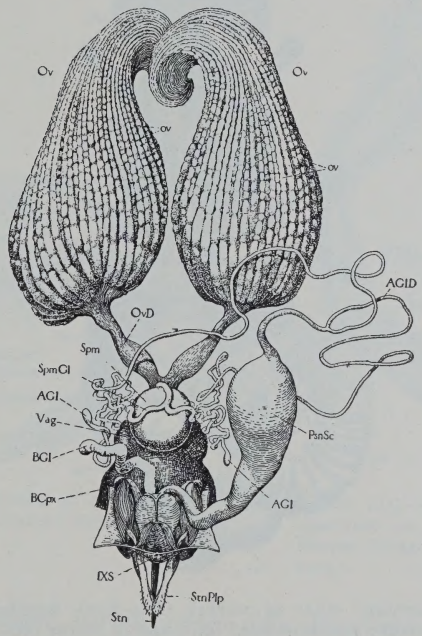

FIG. 147.—Reproductive organs, sting and poison glands of queen, dorsal view. *AGl*, acid gland of sting; *AGlD*, duct of acid gland to sting; *BCpx*, bursa copulatrix; *BGl*, alkaline gland of sting; *Ov*, ovary; *OvD*, oviduct; *PsnSc*, poison sac of sting; *Spm*, spermatheca; *SpmGl*, spermathecal gland; *Stn*, sting; *StnPlp*, palpus-like appendages of the sting; *Vag*, vagina. (Snodgrass, United States Department of Agriculture.)

The eggs that hatch into queens or workers are fertilized and those that produce drones are unfertilized. By far the greater number of eggs laid by the queen are fertilized, for the workers greatly outnumber the drones. It is difficult to explain how the queen can lay both fertilized and unfertilized eggs. If it be an instinct, then it

is a most highly specialized one, for the usual composition of the colony is maintained from year to year even when a new queen from a different race is introduced into the hive.

The method by which drones are produced is termed *parthenogenesis* or *asexual reproduction*. This is common among the insects. Parthenogenesis should not be confused with fission in paramecia or budding in hydra, for the drones develop from an egg that is just like all of the other eggs except that it is not fertilized.

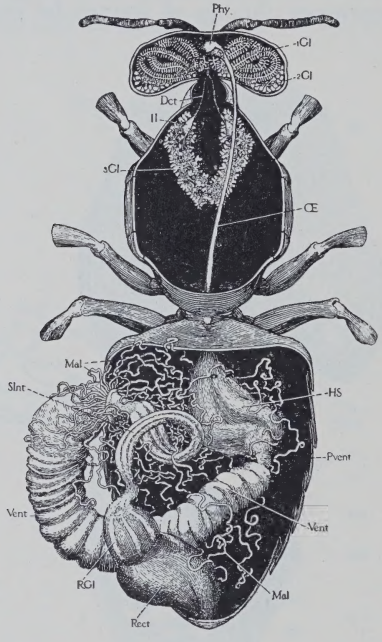

FIG. 148. — Alimentary canal of worker (*Phy-Rect*), together with pharyngeal glands (*1Gl*) and salivary glands of head (*2Gl*) and of thorax (*3Gl*), as seen by cutting body open from above and pulling the ventriculus (*Vent*) out to left. *Dct*, duct; *1Gl*, large pharyngeal gland in anterior part of head; *2Gl*, salivary gland in head; *3Gl*, thoracic salivary gland; *HS*, honey stomach; *Mal*, Malpighian tubules; *OE*, esophagus; *Phy*, pharynx; *Pvent*, proventriculus; *Rect.*, rectum; *RGl*, rectal glands; *Slnt*, small intestine; *Vent*, ventriculus. (Snodgrass, United States Department of Agriculture.)

Honey.—The annual crop of honey in the United States alone is estimated to be worth about $17,000,000 as food for man. Man has been eating honey since ancient times and critically studying all phases of the life of the bee for the past forty years. But as yet he can describe in only a general way how the bee makes honey.

The collecting of honey is done entirely by the workers, who suck the nectar from plants. This they swallow and store in the honey stomach (Fig. 148, *HS*), until they return to the hive, when it is deposited in a cell in the honey comb. "Here it is ripened into honey. This ripening consists in the removal of the surplus moisture, the water in honey usually being about 20 per cent. of the total, while nectar is often over 60 per cent. water. The chemical composition of nectars has not been sufficiently studied, and, indeed,

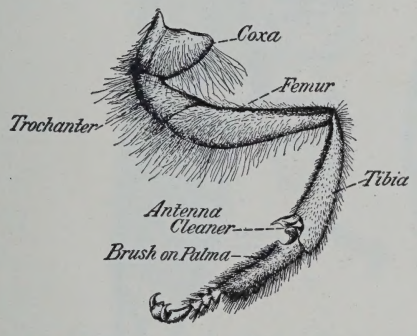

FIG. 149.—Left foreleg of a worker bee. (Casteel, United States Department of Agriculture.)

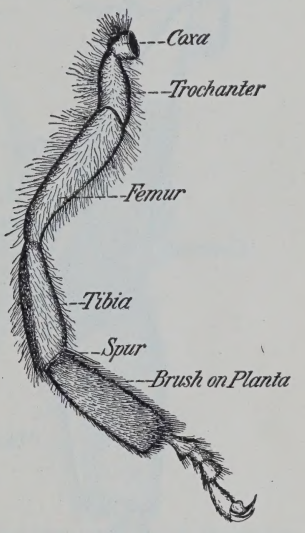

FIG. 150.—Left middle leg of a worker bee. (Casteel, United States Department of Agriculture.)

this is a hard problem, because of the difficulty of obtaining sufficient quantities without modification. Enough is known, however, to allow the assumption that the ripening process also includes the changing of sucrose (cane sugar) into invert sugars (dextrose and levulose)."

Pollen Collecting.—Closely associated with the gathering of nectar is the work in collecting pollen. This introduces one to a highly specialized series of instincts that should be compared to the special responses of the frog as illustrated on page 92.

The three pairs of legs and the hairs on the body and legs are the main structures that need to be considered. Figs. 149–153 show the legs and their hairs. The tibia of the last pair of legs is especially

modified to hold pollen, and the term pollen-basket or corbicula is given to this region.

"A very complete knowledge of the pollen-gathering behavior of the worker honey bee may be obtained by a study of the actions of bees which are working upon a plant which yields pollen in abundance. Sweet corn is an ideal plant for this purpose, and it will be used as a basis for the description which follows.

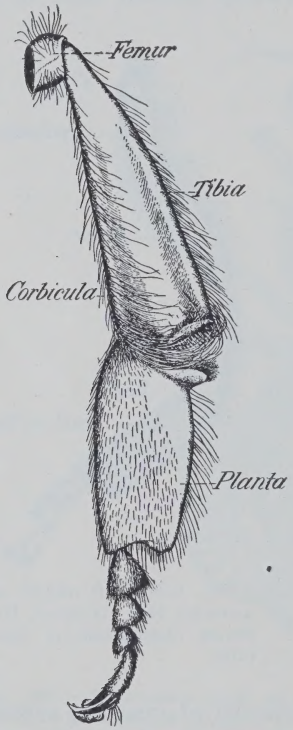

FIG. 151.—Outer surface of the left hind leg of a worker bee. (Casteel, United States Department of Agriculture.

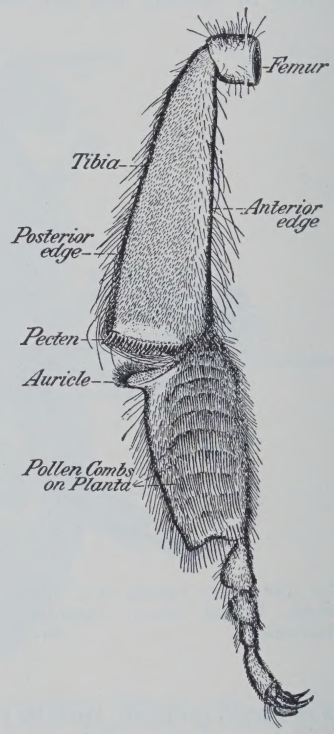

FIG. 152.—Inner surface of the left hind leg of a worker bee. (Casteel, United States Department of Agriculture.)

"In attempting to outline the method by which pollen is manipulated the writer wishes it to be understood that he is recounting that which he has seen and that the description is not necessarily complete, although he is of the opinion that it is very nearly so. The movements of the legs and of the mouth parts are so rapid and so many members are in action at once that it is impossible for the eye to follow all at the same time. However, long-continued observation,

assisted by the study of instantaneous photographs, gives confidence that the statements recorded are accurate, although some movement may have escaped notice.

"To obtain pollen from corn the bee must find a tassel in the right stage of ripeness, with flowers open and stamens hanging from them. The bee alights upon a spike and crawls along it, clinging to the pendent anthers. It crawls over the anthers, going from one flower to another along the spike, being all the while busily engaged in the task of obtaining pollen. This reaches its body in several ways.

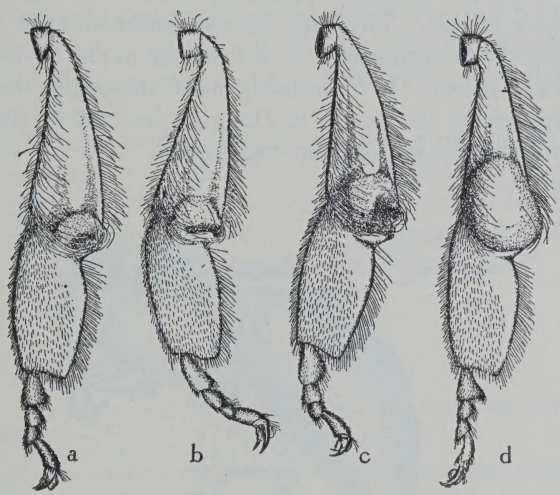

FIG. 153.—Camera drawings of the left hind legs of worker bees to show the manner in which pollen enters the basket. *a* shows a leg taken from a bee which is just beginning to collect. It had crawled over a few flowers and had flown in the air about five seconds at the time of capture. The pollen mass lies at the entrance of the baskets, covering over the fine hairs which lie along this margin and the seven or eight short stiff spines which spring from the floor of the corbicula immediately above its lower edge. As yet the pollen has not come in contact with the one long hair which rises from the floor and arches over the entrance. The planta is extended, thus lowering the auricle. *b* represents a slightly later stage, showing the increase of pollen. The planta is flexed, raising the auricle. The hairs which extend outward and upward from the lateral edge of the auricle press upon the lower and outer surface of the small pollen mass, retaining it and guiding it upward into the basket. *c*, *d*, represent slightly later stages in the successive processes by which additional pollen enters the basket. (Casteel, United States Department of Agriculture.)

"As the bee moves over the anthers it uses its mandibles and tongue, biting the anthers and licking them and securing a considerable amount of pollen upon these parts. This pollen becomes moist and sticky, since it is mingled with fluid from the mouth. A considerable amount of pollen is dislodged from the anthers as the

bee moves over them. All of the legs receive a supply of this free pollen and much adheres to the hairs which cover the body, more particularly to those upon the ventral surface. This free pollen is dry and powdery and is very different in appearance from the moist pollen masses with which the bee returns to the hive. Before the return journey this pollen must be transferred to baskets and securely packed in them.

"After the bee has traversed a few flowers along the spike and has become well supplied with free pollen it begins to collect it from its body, head and forward appendages and to transfer it to the posterior pair of legs. This may be accomplished while the bee is resting upon the flower or while it is hovering in the air before seeking additional pollen. It is probably more thoroughly and rapidly accomplished while the bee is in the air, since all of the legs are then free to function in the gathering process.

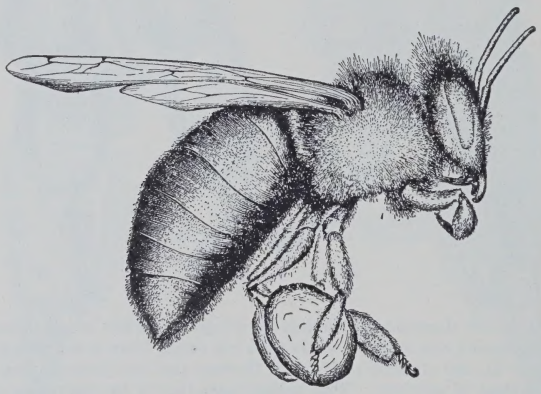

FIG. 154.—A bee upon the wing, showing the position of the middle legs when they touch and pat down the pollen masses. A very slight amount of pollen reaches the corbiculæ through this movement. (Casteel, United States Department of Agriculture.)

"If the collecting bee is seized with forceps and examined after it has crawled over the stamens of a few flowers of the corn its legs and the ventral surface of its body are found to be thickly powdered over with pollen. If the bee hovers in the air for a few moments and is then examined very little pollen is found upon the body or upon the legs, except the masses within the pollen-baskets. While in the air it has accomplished the work of collecting some of the scattered grains and of storing them in the baskets while others have been brushed from the body. In attempting to describe the

movements by which this result is accomplished it will be best first to sketch briefly the roles of the three pairs of legs. They are as follows:

"(*a*) The first pair of legs remove the scattered pollen from the head and the region of the neck, and the pollen that has been moistened by fluid substances from the mouth.

"(*b*) The second pair of legs remove scattered pollen from the thorax, more particularly from the vental region, and they receive the pollen that has been collected by the first pair of legs.

"(*c*) The third pair of legs collect a little of the scattered pollen from the abdomen and they receive pollen that has been collected by the second pair. Nearly all of this pollen is collected by the pollen combs of the hind legs and is transferred from the combs to the pollen-baskets."

The details connected with the activities of the mouth parts and the detailed action of each pair of legs illustrate a very complex series of reflexes that help one to understand why the bee is regarded as such a highly specialized animal. This account of the honey bee has been taken from the following:

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PHILLIPS: Beekeeping.

SNODGRASS: The Anatomy of the Honey Bee, Bureau of Entomology, Technical Series No. 18.

PART IV.

THEORETICAL INTERPRETATIONS.

CHAPTER XIX.

THE SCIENTIFIC METHOD.

"All writers on the principles of science agree that man has as yet discovered nothing except a little of the order of Nature, and that the reason why events occur in one order rather than another, or even why they occur in any order, is a mystery to which Nature gives us no answer."[1]

"Looking back through the prodigious vista of the past, I find no record on the commencement of life, and therefore I am devoid of any means of forming a definite conclusion as to the conditions of its appearance. Belief, in the scientific sense of the word, is a serious matter, and needs strong foundation. To say, therefore, in the admitted absence of evidence, that I have any belief as to the mode in which existing forms of life have originated, would be using words in a wrong sense. But expectation is permissible where belief is not; and if it were given to me to look beyond the abyss of geologically recorded time to the still more remote period when the earth was passing through physical and chemical conditions, which it can no more see again than a man can recall his infancy, I should expect to be a witness of the evolution of living protoplasm from not living matter. I should expect to see it appear under forms of great simplicity, endowed, like existing fungi, with the power of determining the formation of new protoplasm from such matter as ammonium carbonates, oxalates and tartrates, alkaline and earthy phosphates and water without the aid of light. That is the expectation to which analogous reasoning leads me; *but I beg you once more to recollect that I have no right to call my opinion anything but an act of philosophical*

[1] William Keith Brooks, for many years Professor of Zoölogy in Johns Hopkins University.

faith." Huxley in *Biogenesis and Abiogenesis*, 1870. Italics by the writer.

These two quotations from eminent students of zoölogy constitute a challenge to our ever ready practice of generalizing and they should force us to inquire into the method by means of which progress in our knowledge of life has been gained. There have been golden ages in Greece and Rome in the past which some feel will never be surpassed but there have been more additions to our knowledge of Nature in the past fifty years than in all of past history. The age in which we are now living will be known in history as the age of science, an age in which great advance in material welfare, comfort and intellectual outlook for all mankind were the outstanding characteristics. Thus civilization has been moving forward very rapidly during this short time as man has gained control of Nature's processes. It is no accident that such stupendous changes should be possible for we have been applying generally a method of study that has enabled us to do in a large way what a few men were trying to do in the past. In one sense the scientific method of working and thinking belongs to a course in philosophy but the plan on which we have been conducting our study justifies a brief summary of its main features as we turn for a time to some of the theoretical interpretations of biology.

In this general section we shall place our emphasis on the explanations and theories which men have formulated in their attempt to comprehend the relationships, adaptations, distributions and development of all forms of life. It is important that we make a clear distinction between what men think the facts mean and the facts themselves. Facts cannot be altered or set aside. They continue to exist irrespective of the conflicting efforts of man to tell what they mean. The reason that we can speak or write with confidence about such vast data in biology is due to the fact that many men have had a passion for accuracy of observation which they have recorded with precision. "First make sure of the facts" is the first law of the scientists. The unscientific mind is content with "nearly" or "almost" but these words never describe Nature. One of the most grevious offences that a scientific writer can commit is to make false statements about his facts. We must be able to accept them unquestioningly. While we gladly permit a wide range to man in his efforts to interpret these facts, none is permissible in his statement of the facts. "Nature knows no trifling; she is always sincere, always serious, always stern; she is always right, and the errors and mistakes are invariably ours." (Goethe.) The first point to be emphasized in the working of the

scientific method is the adoption of standard measurements whenever possible in order that the highest degree of accuracy shall be attained in the description of the facts. In biology it has been difficult to apply measurements to activities and shades of color, or to determine just how energy is utilized. So that the biologist is a judge as well as a witness. He makes his investigation and has to adopt a plan which shall apply to his particular group of facts for which at present there are no standard measurements such as obtain in physics. It is this feature of biology that beginning students find so difficult.

The scientific method can be traced back into the misty past where some unknown men made the first accurate observations on the heavenly bodies. The reason that their conclusions have stood the test of time is due to the fact that they employed a method which was so accurate that others could apply it and verify their observations. Hipparchus as early as 160 B.C. made his deduction after a study of the causes associated with the revolution of many of the heavenly bodies. After him a period of three hundred years elapsed before this method was again successfully employed and the conclusions of Ptolemy, 140 A.D., still constitute an important part of the fundamental knowledge of our oldest science, Astronomy.

As we have continually applied the scientific method of study to our work, it has been relatively easy to collect the facts and to arrange them into groups but our attempts to state the fundamental generalizations were beset with many difficulties, the most important of which is the fragmentary character of our knowledge of life processes. Biology presents difficulties which chemistry and physics do not offer because it deals with more kinds of things, all of which are organized into the most complex structures known. The chemical and physical properties of water, sugar, iron, etc., are elementary in their simplicity in comparison with an amœba. But an amœba is one of the simplest of living things. As we ascend the scale of animal and plant life, complexity takes the place of simplicity. To formulate generalizations that shall be applicable to more than 1,000,000 different species of organisms known to the biologist represents the highest development of our science.

The simple results expressed in the few generalizations that you have learned in this course are the fruit of an enormous amount of work by many investigators. But work alone could never have brought order out of all of the confusion. The work had to be done according to some plan; this plan we know as the scientific method of thinking.

When Lyell, in 1830, announced in his *Principles of Geology* that the former changes in the earth's surface could be explained by a study of the causes now in operation, he formulated for the first time the main points in the scientific method. Darwin was one of the first to employ it in biology. Let him tell how he did it: "By collecting all facts which bore in any way on the variation of animals and plants under domestication and nature, some light might perhaps be thrown on the whole subject. My first note-book was opened in July, 1837. I worked on true Baconian principles, and, without any theory, collected facts on a wholesale scale, more especially with respect to domesticated production, by printed inquiries, by conversation with skilful breeders and gardners, by extensive reading. When I see the list of books of all kinds which I read and abstracted, including whole series of journals and transactions, I am surprised at my own industry. I soon perceived that selection was the keynote of man's success in making useful races of animals and plants. But how selection could be applied to organisms living in a state of nature remained for some time a mystery."[1]

After Darwin had worked for about twenty years he was able to classify his numerous observations and formulate his famous theory of the Struggle for Existence. During the past seventy-five years this method of work has dominated science and is responsible in a large measure for the marvelous progress in this field of learning.

If we separate the scientific method into its parts a clearer notion of how it operates and how we may operate it is obtained. These parts are cause, effect, classification.

1. The scientific method implies that the happenings of today are the outgrowth and continuation of some previous happenings which it is customary to speak of as causes. A metaphysical first cause has no place in the scientific method simply because it is something that is unknown. When a happening is repeatedly found to be associated with an equally constant result it is spoken of as the cause of the result. In the refinements of analysis it is proper to ask why it is a cause, whether it is the only cause or what causes are associated in producing a given result.

2. When a given fact is observed to be a cause, then the one or more happenings which it initiates are designated as effects. There is thus a definite relationship between cause and effect which constitutes the essence of the scientific method. It implies that the results cannot

[1] The Life and Letters of Charles Darwin, vol. ii, p. 83.

take place without a given cause. When this is applied to our every-day knowledge one says that the leaves appear in their season and that a maple leaf does not grow on an elm tree. Fruit time and harvest are preceded by an orderly series of events, each linked to each as in a chain. This principle is not limited to organic life. The passing street car, the torrential brook in spring time freshets or the destructive tornado are to be understood only after a close study of certain particular causes. To express the same idea in a different way, one may say that every happening, every material thing in the universe of today has had a continuous history. The happenings of today become the history of tomorrow, and it is necessary to know the history of yesterday if one would understand the happenings of today. *The scientific method implies that all observations shall be made in such a way that they can be repeated, controlled*[1] *and verified by subsequent observers.*

3. Simply to trace the relationship between cause and effect is to stop short, to leave the job incomplete. Nor is the mere collection of a vast number of observations, facts or cause and effect relations, especially helpful unless the next step is taken which is classification. In all of your laboratory study the work has been carefully arranged and you have been guided in your collection of facts. If you will review any one of the laboratory topics you will discover that you collected your facts in an orderly manner. For example, as you described the external parts of *Rana pipiens* the body was divided into head, trunk and limbs, with specific facts to be ascertained in connection with each part. When you had completed this study, you had worked out many of the species characters of *Rana pipiens.* In a similar way the facts about all organisms are classified and order is introduced into man's method of dealing with living things. After the facts have been properly classified and general principles or laws formulated that apply to large numbers of organisms, such as the generalizations that can be stated for all animals with backbones or for all flowering plants, then men can attempt to explain their meaning —to philosophize about them.

Each new fact placed in its proper relation to a larger grouping of facts enables us by so much to anticipate nature, in short sets us free and gives new meaning to the saying "The truth shall make you free." So far as the existence of the accumulated facts and generalizations of science are concerned, they have existed as long as man has

[1] The word "controlled" has a technical meaning referring especially to verified repeated experiments.

lived and many of them much longer. But for early man they were unknown and, so far as he could take advantage of them, non-existent. In the same way they are non-existent for many persons even in this age because they have no actual knowledge of them. The more man comes to understand the relationships existing between antecedent happenings and consequent results the greater is his progress and the more economy he can introduce into his thinking.

We may regard the scientific method as furnishing the rules governing man's attempt to acquire knowledge of Nature and supplying the facts which everyone is required to consider who offers a philosophic explanation of life.

Liebig wrote in his old age "The majority of our controversies arise from the fact that we are too much in the habit of attributing to one cause, that which is produced by several." This important generalization needs to be emphasized in our time when hasty conclusions are being spread abroad as a "cure all" for the conditions of the age.

Man has come to have almost complete control of the inorganic universe through the application of the scientific method of thinking. The great generalizations of science are established and he now turns the greater part of his attention to their application. In all of these manifold applications, man is able actually to create nothing, he can only combine materials or take advantage of principles. We really make our advances when *new facts and phenomena are discovered and their relationships established.* In this way the gaps in our knowledge are lessened and by so much more we come to understand the laws of Nature. For these laws are really only a specific phrasing of the relationships that have always existed between the facts, even before man observed them. Man lives in harmony with Nature only when he obeys her laws; he can profit from Nature only when he utilizes her laws; he can comprehend Nature and his relation to her only when he recognizes both her unity and her variety.

CHAPTER XX.

EVOLUTION.

Evolution Defined.—There is so much popular confusion concerning the use of the term evolution that we are quoting extensively from a number of authorities. As you study these, observe (1) That there is more than one form of evolution; (2) that evolution is taking place at the present time; (3) that a clear distinction is to be made between the "fact" of evolution and the causes which have and do operate to bring about evolution; (4) that the method of evolution is a scientific problem; and (5) that evolution is not materialism.

"Evolution is the gradual development from the simple unorganized condition of primal matter to the complex structure of the physical universe; and in like manner, from the beginning of organic life on the habitable planet, a gradual unfolding and branching out into all the varied forms of beings which constitute the animal and plant kingdoms. The first is called Inorganic, the last Organic Evolution." Richard Swann Lull, *Organic Evolution* (1917), page 6.

"The Doctrine of Evolution is a body of principles and facts concerning the present condition and past history of the living and lifeless things that make up the universe. It teaches that natural processes have gone on in the earlier ages of the world as they do today, and that natural forces have ordered the production of all things about which we know." Henry Edward Crampton, *The Doctrine of Evolution* (1911), page 1.

"Organic evolution means that the present is the child of the past and the parent of the future. It is not a power or a principle; it is a process—a process of becoming. It means that the present day animals and plants and all the subtle interrelations between them have arisen in a natural, knowable way from the preceding state of affairs on the whole somewhat simpler, and that again from forms and interrelations simpler still, and so on backward and backward for millions of years until we lose all clues in the thick mist that hangs over life's beginnings." J. Arthur Thomson, *Outline of Science,* page 56, vol. I.

"The demonstration of evolution as a universal law of living nature is the great intellectual achievement of the nineteenth century.

Evolution has outgrown the rank of a theory, for it has won a place in natural law beside Newton's law of gravitation, and in one sense holds a still higher rank, because evolution is the universal master, while gravitation is among its many agents. Nor is the law of evolution any longer to be associated with any single name, not even with that of Darwin, who was its greatest exponent. It is natural that evolution and Darwinism should be closely connected in many minds, but we must keep clear the distinction that evolution is a law, while Darwinism is merely one of the several ways of interpreting the workings of this law.

"Our present state of opinion is this: We know to some extent how plants and animals and man evolve; we do not know why they evolve. We know, for example, that there has existed a more or less complete chain of beings from nomad to man, that the one-toed horse had a four-toed ancestor, that man has descended from an unknown ape-like form somewhere in the Tertiary. We know not only those larger chains of descent, but many of the minute details of these transformations. We do not know their internal causes, for none of the explanations which have in turn been offered during the last hundred years satisfies the demands of observation, of experiment, of reason. It is best frankly to acknowledge that the chief causes of the orderly evolution of the germ are still entirely unknown, and that our search must take an entirely fresh start." H. F. Osborn, *The Origin and Evolution of Life* (Charles Scribner's Sons), 1918, pages 8–10.

"In evolution, it is true, the last barrier is broken down, and the whole domain of Nature is now subject to law; but it is only the last; the march of science has been in the same direction all the time. In a word, evolution is not only not identical with materialism, but, to the deep thinker, it has not added a feather's weight to its probability or reasonableness. Evolution is one thing and materialism quite another. The one is an established law of Nature, the other an unwarranted and hasty inference from that law." Le Conte.

"When I first came to the notion, of a succession of extinction of species, and creation of new ones, going on perpetually now, and through an indefinite period of the past, and to continue for ages to come, all in accommodation to the changes which must continue in the inanimate and habitable earth, the idea struck me as the grandest which I had ever conceived, so far as regards the attributes of the presiding mind." *From a letter of Sir Charles Lyell to Sir John Herschel,* 1836.

"The question of whether organic evolution is a fact has been

sharply before the world now for forty years, and has been studied from many standpoints. Manifestly one of the first questions to be asked upon this subject would be whether the living world has had a continuous history. If evolution is a fact it must follow that the species of today have been produced from the species of yesterday as the result of forces acting upon them. If such is the case then the history of species must have been as truly a continuous one as has been the history of the races of men. If, on the other hand, the species of animals and plants have appeared by creative fiats we should expect no such continuous history; or rather there would be no history of animals and plants, but only separate histories of individual species." Conn, *The Method of Evolution,* page 8.

"Organic evolution is not a theory of the origin of men from monkeys, but is concerned with the origin and development of all the animal and plant bodies which now exist; and it is part of the larger theory of cosmic evolution, which postulates that the visible universe has reached its present state by a process of *change.* This change is going forward in the present, and will, presumably, continue in the future. Concepts of infinite space and infinite time are involved. Man's claim to importance in the dynamic system thus revealed, lies not in the pretense that this planet was prepared for his coming, but in the claim that he transcends the visible universe in so far as he comprehends it." Curtis, *Science and Human Affairs,* page 156.

Organic evolution in brief is the theory that living organisms have descended from earlier and simpler forms of life by a natural process.

Evolution a Fact.—In the quotations just reviewed, repeated reference is made to the difference of opinion about the theories of how evolution was brought about in both the inorganic and organic world but all are agreed as to the *fact* of evolution. What is meant by this expression; *The Fact of Evolution?*

The conception of evolution has come to dominate all of our thinking so completely that we seldom raise this question. History is a word that typifies this idea indicating that events can be traced to their sources; and that in turn these sources were events that arose from still more distant happenings. While we cannot entirely reconstruct such distant events, we can explain them in terms of how similar events take place today. A long time ago Buffon said, "To understand what has happened, and even what will happen, we have only to examine what is happening." In a similar manner we depict the history of the earth and read the story recorded in the successive strata of rocks. Evolution implies that the events connected with

the formation of the layers of the earth took place in an orderly manner and by natural processes. No other explanation accounts as satisfactorily for these events so there has slowly come to be a conviction that the older rocks are covered by the younger rocks, all of which arose through a natural series of changes. This in brief is what is meant by the *fact* of evolution in connection with the formation of our earth.

The history of the steps through which animals and plants pass is in a general way clearly understood and constitutes a large mass of verifiable facts. They always begin in simplicity and grow to complexity if belonging to the higher classes. *There are no breaks in this continuity of life.*

In all of the vast numerical complexity of life there is: (1) A common unit of structure, the cell; (2) a common basis of structure, protoplasm; and (3) an identity in all of the fundamental life processes. These several groups of *observable* facts constitute a combination of relationships and adaptations that, it is believed, have resulted in the past and present forms of life and it is these results which are most satisfactorily explained by evolution. This is what is meant by the *fact* of evolution in connection with life.

With all of these characteristics held in common, by all of the different species of animals and plants, how is it possible for new structures to arise? The fact to be emphasized is that the fundamental structures "in biology are, the organs, cells, chromosomes, the hereditary characters, inheritance units, or the molecules of which such units are composed. Evolution does not consist in the creation *de novo* of molecules, units, characters, organs, or functions, but rather in new combinations of them. New combinations give rise to new qualities." E. G. Conklin, *Direction of Human Evolution*, pages 7–10.

No one can intelligently study, for example, the skeleton of vertebrates including man, without being convinced (1) that there is but a limited number of different bones; (2) that the numerous differences consist in modifications of these bones and not in the creation of new bones, which is a conclusive illustration (and many others might be mentioned), of Conklin's generalization. (See discussion of Homology).

An Evolutionist.—The philosophical biologist is an evolutionist, who at present does not undertake to explain the origin of protoplasm or why it has its unique organization; but he does attempt to formulate as complete an *explanation* as possbile of the method by which the

change in organic nature has been produced. He accepts the fact of evolution. Paraphrasing in part we may say that the explanation of evolution is associated with the idea that nothing can happen without a cause; that nothing can disappear without leaving traces; and that all things have their origin in the things which precede them and engender the things which follow them. (Delage and Goldsmith, *The Theories of Evolution*, page 5.) The evolutionist, then, is one who seeks to explain the changes in Nature in terms of matter and energy. His explanations therefore are all proximate because he does not deal with ultimate causes.

Some Problems and Facts with Which the Evolutionist must Deal.—*Importance of Biogenesis.*—As long as there was any doubt concerning the biogenetic law, men had a reasonable basis for questioning the continuity of life. The abiogenetic controversy which had played so large a part in the explanation of life was finally discarded through the conclusive experiments of Pasteur and Tyndall, 1777–1864.

As a result of these controversies extending over twenty centuries, biologists in general became convinced that life with its physical, chemical and biological characteristics (see page 151) must be assumed as having been similar from the beginning. Since there is no scientific explanation for the origin of protoplasm, it is not necessary to require that our hypothesis supply one.

You have observed the fertilized ovum of the frog in segmentation, gastrulation, the formation of germ layers, the gradual organization of organs resulting eventually in a tadpole. This tadpole in turn was seen to have external gills, internal gills and these to be replaced by lungs. Legs appeared, the tail was absorbed, and a frog was formed. This series of events constitutes a group of facts that require an explanation but it must be one that does no violence to these verifiable phenomena. In 1600 Fabricus published drawings showing the development of animals. He preceded Harvey by fifty years in recording correctly some embryonic stages in the higher animals. The idea that the fully-formed organism could possibly arise gradually, changing from a simple embryonic condition into the complex full-grown condition was first emphasized by Harvey in 1651. The clearness of his observations, and the independence of his thinking carried him far beyond his predecessors. So we have come to think of the phrase "omne vivum ex ovo" as having an especial significance ever since his time. For more than two hundred years before the myth of abiogeneses was laid to rest, many scientists held that "all life came from an egg," or as we say now, all life came from preëxisting life.

Since the time of the early embryologists, Harvey, Wolff, Von Baer, Balfour and others, there have been an incredible number of painstaking observations on the transformation of the embryo into an adult organism. No intelligent person ever thinks that there is now or has been any different process in the formation of new individuals.

As the several organisms were studied, it appeared to the earlier observer that they were unfolding or unrolling. These two words suggest that there was a certain organization in the embryo and that the organs of the adult preëxisted. This conception gave rise to the view that the parts *evolved.* Thus there was from the first *the idea that the adult was related to the past.*

The Distinction Between Animals and Plants.—There is no question about the fact that they are different in certain marked respects. Can this difference be accounted for?

Our modern studies indicate with the utmost clearness that the fundamental physical, chemical and biological characteristics of protoplasm are identical in these two kingdoms; and, that the difference really consists in an additional physiological process, the syntheses of organic compounds from the raw elements in Nature, through the influence of chlorophyll which is a distinct vital process. Is it exclusively a process confined to plants or are there intermediate stages?

You have become familiar with the metabolic features of the frog and paramecium. These two stand in sharp contrast with the pleurococcus and the trillium. Between these two groups of organisms, we found euglena that required organic nitrogen, although it is able to manufacture starch. Then there was the yeast that is able to build up its own food from Pasteur's solution which does not contain organic nitrogen. Finally, we examined the metabolism of the bacteria which Fischer indicates live (1) Like green plants; (2) like animals; (3) an intermediate group similar to euglena and yeast. Thus this basal distinction between animals and plants is no longer an unsolved problem.

Origin of Multicellularism.—All living things fall into two general classes: (1) Those consisting of a single cell, and (2) those made up of many cells. The origin of multicellularism was for a long time beyond the grasp of men, but in recent years more extensive observation reveal a number of organisms that indicate how the first steps in integration and differentiation began. But the explanation that satisfactorily indicates how this great gap was bridged must be one that can be applied to the other outstanding biological problems.

Just as soon as organisms began to show differentiation of tissues, certain cells were set apart for the purpose of reproduction and were nourished and protected by the remaining cells in the organism. The sex cells remained simple while the other tissues became specialized for locomotion, food-getting, digestion, etc. In vorticella the entire organism is at irregular intervals transformed into a germ cell, becoming either a macrogamete or microgamete. The fusion of the macrogamete with the microgamete gives rise to the *zygote;* and, after some nuclear reorganization, this new organism becomes again a metabolic cell. Differentiation in multicellularism simply prevents any such reversibility and the tissues when once formed rarely revert to the reproduction state unless one regards regeneration as such a reversion. The beginning of cross fertilization is indicated in the zygote formation in unicellular organisms which indicates that this important characteristic did not originate in the higher animals and plants, although much more specialized in them. The changes that take place in organisms resulting in either male or female are associated in origin with that of multicellularism.

The Phylum.—You first studied the phylum Chordata, then Protozoa, Protophyta, Cœlenterata, Arthropoda and others. These terms stand for great groups of organisms that have many features in common. Between many of them there does not appear to be any clear line or relationship. Mollusca and Echinodermata are two such phyla among the invertebrates; while the origin of the chordata is one of the major zoölogical problems still remaining unsolved.

Conklin has well described the question of phyla in the following: "Among animals no new phyla have appeared since the vertebrates in the Silurian or perhaps even earlier; no new classes since mammals in the Triassic and birds in the Jurassic. In the evolution of animals only about fourteen times in the whole history of life have new phyletic paths been found and several of these were blind alleys that led nowhere. The climax of the progressive evolution of fishes was probably reached in the Devonian, of amphibians in the Permian, of reptiles in the Mesozoic. In all these classes the formation of new species has been going on more or less continuously, but progressive evolution in the sense of increasing complexity of organization has reached or passed its climax."

Species.—No one knows exactly how many different kinds of fossil and living species there have been since life first began. From the several studies that have been made, we estimate that there are approximately 1,000,000 different species. Each species maintained

its identity for a certain period before becoming extinct. The law of biogenesis requires that we accept a definite genetic relationship between this large number of distinct species, although the relationship is in most instances very distant.

Other Problems.—In addition to these clearly defined problems, which any explanation of organic evolution must consider, there are in addition such general topics as Adaptation, Distribution, Parasitism, Disease, and the relation of environment to all of these questions.

As the evolutionist undertakes to explain the past and present forms of life he discovers that he has at his disposal the fact of variation and the fact of heredity.

Variation.—Whenever we study any large number of individuals belonging to a given species, it is found that there is a certain range of variation, and these variations consist in differences in the size or strength of structures, or differences in the rate of metabolic reaction. These variations constitute the material out of which different structures are formed and change results.

Heredity.—Heredity is the transmission from the parent to the offspring of the similar structural features that characterize the species to which the parent belongs, but with certain differences that give individuality to the offspring.

In order that organisms may undergo change, variations must persist from generation to generation. The explanation of how organisms develop these differences and still retain their similarities to other members of their class has received so much attention that it constitutes one of the important fields of biological study, known as *Genetics*. We shall first take up the study of genetics and indicate its bearing on organic evolution; then the question of Lamarck's and Darwin's *explanations* will be considered. This will be followed by an examination of the evidences of evolution under the following headings:

The Significance of Fossils.
Geographical Distribution.
General Adaptations.
Parasitism.
Adaptation and Disease.

CHAPTER XXI.

GENETICS.

Genetics Defined.—Genetics is the study of the manner in which the differences and similarities in any group of organisms are transmitted from parent to offspring. It includes the subjects of *variation* and *heredity.*

Variation.—Every organism that we have studied was given a specific name but if you had examined a large number of individuals, a certain range of variation would have been discovered. There is no exact number of somites, for example, in Lumbricus terrestris that constitutes the species characters; Pearl found that the range of somites is from 79 to 174 and that the length of the earthworm does not depend on the number of somites. Even microscopic animals like paramecium show differences that Jennings groups into races.

"The individuals of any race vary much among themselves, but these differences are matters of growth and environment and are not inherited. What is produced in reproduction depends on the fundamental constitution of the race, not on the peculiarities of the individual parent. The fundamental constitution of the race is resistant to all sorts of influences; it changes only in excessively rare instances and for unknown cause. In a study of thousands of individuals of paramecium, through hundreds of generations hardly a single case of such change was observed. Most differences between individuals are purely temporary and without significance in inheritance; the others are permanent diversities between constant races. Systematic and continued selection is without effect in a pure race, and in a mixture of races its effect consists in isolating the existing races, not in producing anything new." (Fig. 155.)

Such differences exist in many species especially if they have been in existence for a long time and have lived in a varied environment. In some species the range of variation is so great that experts cannot agree whether there should be one or several species. The various changes in the shape, size or color of the structural features of a species express the degree of change that takes place and is a measure of the range or degree of variation as the organism lives from year to year under a slowly changing environment.

The critical study of these minor modifications is the chief criterion in distinguishing species and this is so important that special methods have been devised for placing the study on a scientific basis. The grasshopper bears on the tibia of the jumping leg two rows of spines (Fig. 156) known as the outer and inner rows. These spines vary in

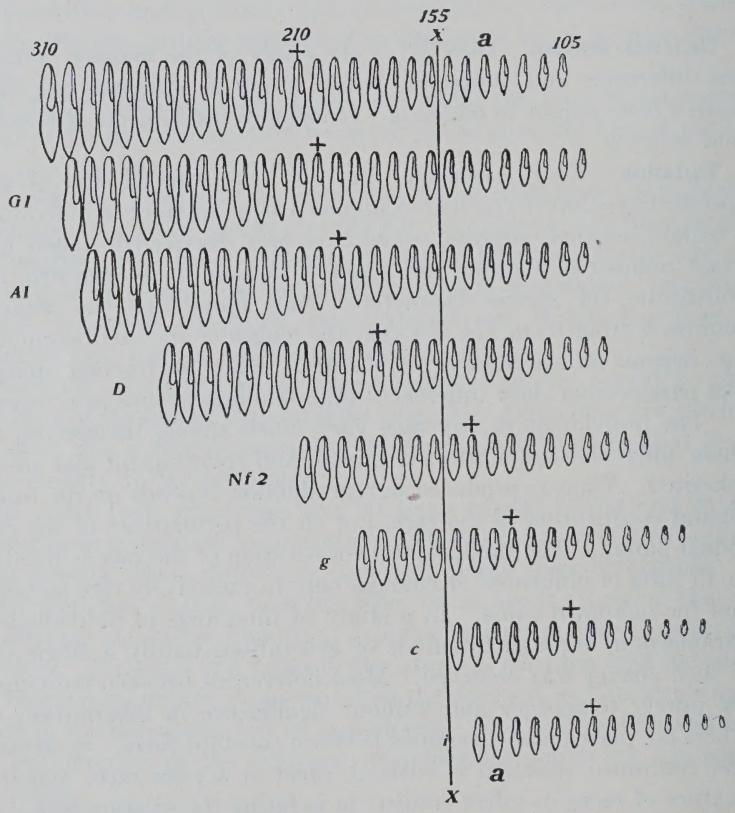


FIG. 155.—Diagram of the species of *paramecium* as made up of eight different races. Each horizontal row represents a single race. The individual showing the mean size in each race is indicated by a cross placed above it. The mean of the entire lot is shown at x, x. The numbers show the measurements in microns. The magnification is about 43 diameters. (Jennings.)

number in both sexes, and yet the extent of the variation is constant for each species, which thus affords a distinguishing character in classification.

In a study of variation some such definite structures as spines are selected which can be measured or counted, and manifestly there

are many of these in most organisms. Such parts are technically called "characters." The number of tibial spines, the length of the body and the color markings of the grasshopper are all characters. In a similar way one can select characters in plants, such as the number of petals, length of petiole or subdivisions of the leaf.

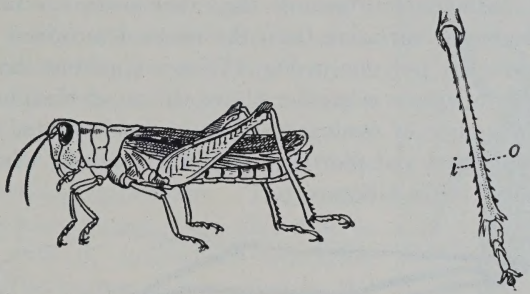


FIG. 156.—The red-legged locust. *Melanoplus femur-rubrum*, and enlarged hind tibia, showing inner (*i*) and outer (*o*) rows of spines. (Kellogg and Bell.)

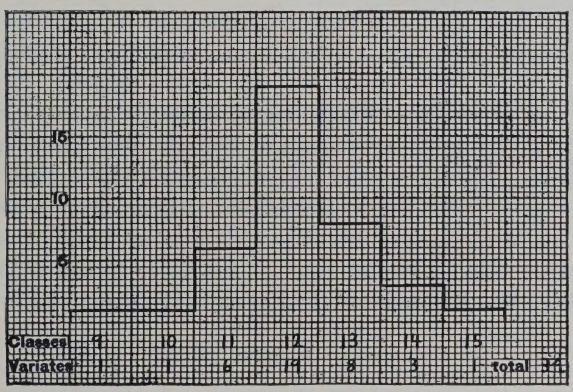


FIG. 157.—Frequency polygon of the variation in number of spines in the outer row of the right tibiæ in 39 male red-legged locusts, *Melanoplus femur-rubrum*. (Kellogg and Bell.)

Kellogg and Bell collected several lots of grasshoppers and examined the extent of the variation in the tibial spines. In lot 1 there were 39 individuals which had from 9 to 15 tibial spines. Most of the grasshoppers had 12 spines. In order to express graphically the kind and extent of variation the results are arranged in the form of a curve (Fig. 157). The term *classes* indicates the form that the variation takes, *i. e.*, the tibial spines number 9, 10, 11, 12, etc. The *variates* are the number of individuals that have 9, 10, 11, 12, etc., tibial spines.

By plotting the results and giving to each variate a definite value and then connecting the several points, a line such as is illustrated in Fig. 157 results. This line is called a frequency polygon or variation curve. In this curve there is one class that has more variates than any other, and for this reason is called the mode or mean class. By means of a mathematical formula the exact mean is established and the exact degree of variation from the mean determined.

In the frequency polygon in Fig. 157 it is apparent that the range of the number of spines is greater above the mean than below, which indicates the course of evolutionary movement. These studies can easily be duplicated and plotted in a similar manner while studying the grasshopper in the laboratory.

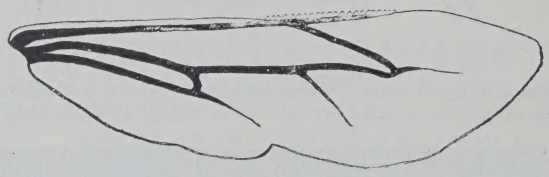


FIG. 158.—Hind wing of honey bee to show position of hooks. (Casteel and Phillips.)

Variations in Insects.—This class of animals has been extensively studied. The method and results of these studies are illustrated by the following: On the second pair of wings of the worker and drone honey bee are found a number of hooks. (Fig. 158.) A study of the hooks in 6 selected lots of drones and 3 lots of workers is shown in the following table. The number of hooks is shown at the top and the number of individuals at the bottom (Casteel and Phillips).

HOOKS ON HIND WING.

DRONES.

Classes	12	16	17	18	19	20	21	22	23	24	25	26	27	28	29	Ave.
I	..	..	..	4	4	8	11	9	4	6	1	1	2	..	..	21.56
II	..	2	1	12	21	23	20	17	2	2	..	..	..	..	..	20.12
III	..	..	..	1	7	12	15	28	14	14	6	2	1	..	..	22.09
IV	..	..	4	10	17	22	27	12	2	5	1	..	..	..	..	20.33
V	..	..	..	4	2	11	10	9	7	1	4	1	..	1	..	21.54
VI	1	..	..	3	3	7	6	23	23	19	6	6	1	..	1	22.42
Variates	1	2	5	34	54	83	89	98	52	47	18	10	4	1	1	

WORKERS.

Classes	17	18	19	20	21	22	32	24	25	26	27	28	29	Ave.
I	..	..	6	9	12	11	6	5	1	..	..	..	..	21.42
II	4	13	42	74	94	61	45	11	4	2	..	..	..	21.08
III	2	11	18	18	33	8	6	4	..	..	..	..	..	20.37
Variates	6	24	66	10	139	80	57	20	5	2	..	..	..	

There are many aspects to the whole subject of variation, the full analysis of which must be left to advanced courses, so that but one more is included. Organs or parts of an organism that have had a relatively recent history in so far as their present size and specialization is concerned tend to vary more than similar structures that have remained unchanged for a much longer period. This is conclusively indicated in Pearl's studies on the crayfish where he compares the degree of variation between the chela and first walking appendage. The length of the claw-joint ranged from 12.1 mm. to 34.1 mm., with 37 individuals averaging 19.6 mm. The corresponding joint in the first walking leg ranged from 4.9 mm. to 10.3 mm. with 46 individuals averaging 6.95 mm., indicating much less variation than in the same part in the chela.

Fig. 159.—Giant tropical beetle in which all parts of the body have developed proportionately except the head. The small object between the first pair of legs is the common potato beetle thus indicating how much larger this insect is than ordinary beetles.

One of the extreme forms that variation has taken in a few animals is illustrated in Figs. 159–162. These insects have overdeveloped until some are giants in size, 159–161; or have greatly lengthened the head region; or the legs are too long 162; or grotesque spines are present on the head 160–161. It seems as if these variations had gotten out of control so far as their usefulness is con-

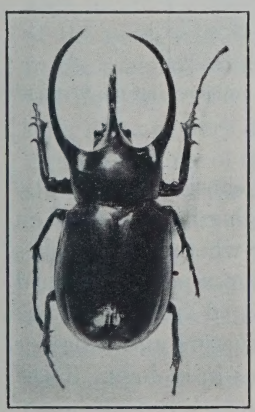


Fig. 160

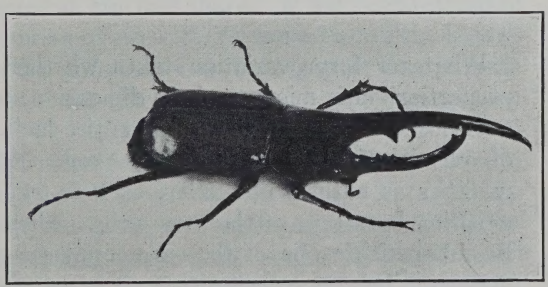


Fig. 161

Figs. 160 and 161.—Giant tropical beetle photographed from dorsal and side. The development of these large processes on the head region restrict the food habits greatly.

cerned and grown to such extremes that these very parts have become a hindrance rather than a help.

Similar bizarre results are found in such vertebrates as the toadfishes, the common peacock and many of the animals which are now extinct, especially in the reptile group, Fig. 98. Such animals are to be thought of as having become over-specialized so that they cannot adapt themselves to changing conditions as well as their more generalized relatives. Newman designates these as old age or senescent variations. He says "Every successful vertebrate class has had a period of youth, when the members were all comparatively generalized; a period of maturity, characterized by adaptive deployment into all of the available life zones; and a period of old age or senescence, characterized by the development of bizarre, over-specialized types, incapable of weathering a world crisis."

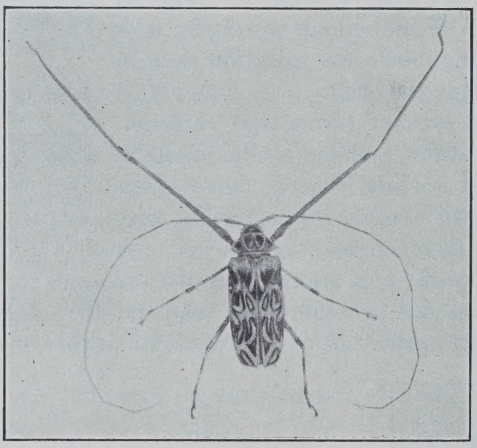


FIG. 162.—Giant tropical beetle that has greatly elongated antennæ and the first pair of legs.

Whatever form variation takes whether it consists of gigantic proportions or is microscopic in dimension; whether it consists of an over-dose of pigmentation or its entire lack; or whether it partakes of physiological characteristics, even such incompletely defined qualities as natural immunity, each is transmitted from parent to offspring by means of the germ cells. Their structure and behavior then, constitute one of the paramount questions in biology. Their discussion belongs to heredity.

Heredity.—Heredity is the name given to one of the aspects of protoplasmic activity in which the history of old relations has a part to play in shaping organisms as we know them. This is a fundamental trait of living matter that serves to transmit not only useful likenesses but many parts that appear in the embryo only or remain rudimentary. No less than 180 vestigial organs are reported for man alone. No system of organs is free from them; the skeleton, the muscles, the nervous and digestive systems all have structures that are important to some of the lower vertebrates but incomplete or functionless in man. These vestigial structures serve to illustrate the hold that this fundamental characteristic has on protoplasm. Some one has described heredity as "organic memory" but this is only suggestive, for mammalian organisms are reproducing with remarkable fidelity ancient structures of that very old period in geology known as the Devonian epoch, which carries us back millions of years beyond the reckoning of man. The regular formation of an embryonic notochord and gill-slits is evidence supporting this statement. In this general sense, the main hereditary picture of organisms was already determined for most living things thousand of years ago. But the picture of its parents which an offspring presents is never identical with the picture that parents present of themselves as the study of variation has already shown. What is known about these remarkable germ cells that transmit from generation to generation not only the history of an organism but also its recently acquired peculiarities?

Germ Cells.—We have already become familiar with these cells especially in the embryology of the frog and have noted their importance in other organisms that have been studied. The setting apart of the germ cells is one of the earliest indications of differentiation in the metazoa which has its beginning in such colonial protozoa as volvox (page 183). It seems to be one of their commonest characteristics to be very different in size and shape. It has been estimated that the volume of the human ovum is 35,000 times that of the human sperm; while in the frog the difference is 6 times greater than in man, and the disparity in size in the chick is still much more than in the frog.

Our earlier studies also indicated that these germ cells never unite to form tissues but are at all times independent cells living in the organism and dependent for their care and nourishment. When the embryo begins segmenting, very early in the process the cell from which the germ cells are to be derived is set apart. (Fig. 163.)

The evidence for this important conclusion is chiefly from the simpler animals but more and more facts are accumulating which justify this statement as of general application. If future investigations establish this claim, then it will be easy to understand how it comes about that the body or soma of an organism and the reproductive substance are not identical. Upon this assumption the germ cells take no part in the formation of the soma or body but remain "a slumbering mass of potentialities which must bide its time to awaken into expression in a subsequent generation. Thus an egg does not develop into a body which in turn makes new germ cells, but body and germ cells are established at the same time, the body harboring and nourishing the germ cells, but not generating them."

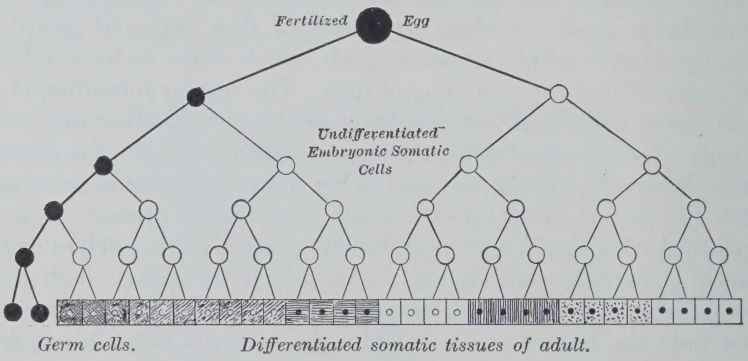


FIG. 163.—Schema of germ and somatic cell differentiation. (After Klebs.)

This assumption in regard to the relation of the germ cells to the body furnishes the basis for the expression *germinal continuity.* This implies that while the bodies of individuals die some of the germinal protoplasm is passed on to another generation without any break, the germinal protoplasm is continuous. When the reproductive cycle begins, these germinal cells become active and usually undergo cell-division giving rise to more germ cells some of which mature and are duly ripened by the process of maturation (page 98).

Chromosomes.—It was emphasized in the study of the frog that the chromatin material of the nucleus was the important structure that the sperm contributed to the ovum in fertilization and that the male parental traits reached the offspring through this avenue only. The same conclusion appears to be true for the female parent so that it is necessary to be more specific about these remarkable bodies. First of all it should be noted that the number of the

chromosomes remains constant for each organism. There are as few as 4 and as many as 160. Man and the tobacco plant have 48 and as already stated, the toad has 12, *Rana temporaria* 10. The size or degree of differentiation in an organism does not determine what the number shall be for some of the protozoa have the larger

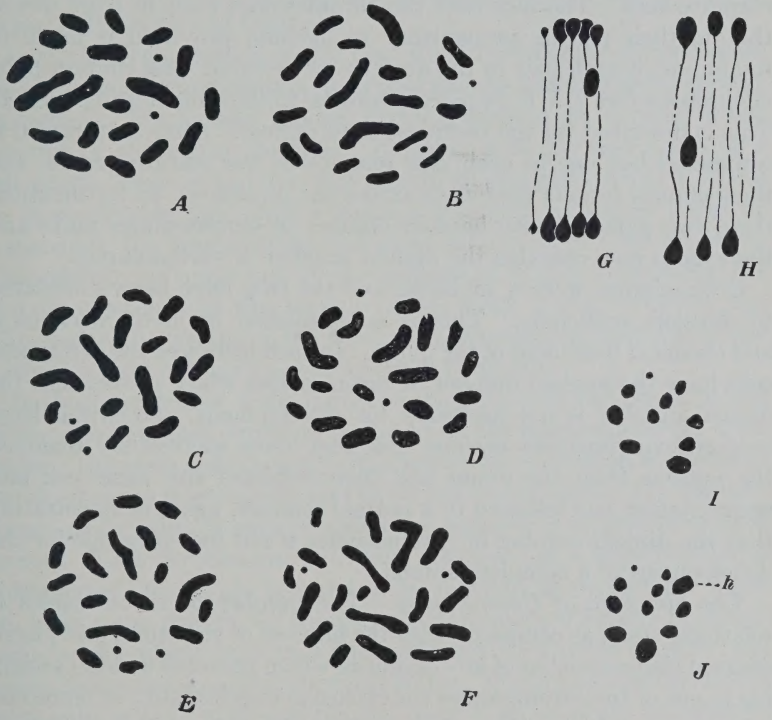


FIG. 164.—Figure to show variation in shape and size of the chromosomes. *Anasa tristis*. *A* to *F*, spermatogonial groups; *G*, *H*, anaphases of second division, showing division of *m*-chromosomes in *G*, and the undivided heterotropic chromosome on both spindles; *I*, *J*, anaphase groups from the same spindle, polar view, second division, showing *m*-chromosome and macrochromosome in each and the heterotropic (*h*) in *J*. While each species has a given number of chromosomes, they are not identical in shape and size. (After Le Fevre and McGill, in Biological Bulletin.)

number. The second important fact about chromosomes, is that they usually vary enough in size and shape so that the trained worker can follow their behavior through maturation and fertilization, Fig. 164. In these changes he finds the chromosomes in pairs, there are two of each size and shape. In sexual reproduction two gametes unite to form a zygote or fertilized ovum. This union introduces

a full set of chromosomes. Similar unions have been taking place ever since this method of perpetuation first occurred in Nature. Unless some means were devised, the zygote would have become possessed of a vast number of chromosomes which we know it has not. Maturation, then is the process in both male and female by means of which the mature gamete is relieved of one-half of the number of chromosomes. The fact that the chromosomes exist in pairs means that in their pairing preparatory to division provision is made to retain one of each pair in the nucleus. The tissue cells contain pairs of chromosomes 2, 5, 6, 24 pairs according to the animal being studied. This is described by the technical term *diploid.* After maturation is completed but one of each pair remains in the mature gamete and the technical term of *haploid* describes the condition. In fertilization, then, two gametes with haploid number of chromosomes unite and the zygote now contains the diploid number of chromosomes.

Echinoderms, worms, mollusks and the frog have been stimulated to develop artificially. This is accomplished by both mechanical and chemical treatment of the ovum. In such instances the embryonic cells have the haploid number of chromosomes which proves that the diploid number is not necessary for development. So skilful have modern experimenters become that they have successfully removed the nucleus from the ovum and then fertilized this same cell and segmentation has followed in a normal manner, again demonstrating that the diploid number of chromosomes is not indispensable for the development of a complete animal.

The Structure of Chromosomes.—The number of chromosomes is relatively small as compared with the number of structural and physiological characteristics of any organism which prevents us from assigning to one of the chromosomes the exclusive responsibility of reproducing a given adult character. Some light on this obscure phase is thrown by studies on the form of the chromatin previous to its condensation into the solid chromosomes. In the more favorable forms for this study numerous minute granules can be recognized which are known as *chromomeres.* The assumption is made that these chromomeres are constant and although very numerous are definite in number for each species. Each individual chromosome is therefore a composite structure with hundreds of individual units or chromomeres. "A certain definite group of these elements makes up each chromosome, and at every cell division this chromosome is reformed from the same group of chromomeres, but the chromosome is definitely organized with respect to the position or locus occupied by each chromomere. At

certain stages in the history of chromosomes, they are simply lines of chromomeres, very much like strings of beads with each bead corresponding to a chromomere. Now it appears probable that all of the chromomeres in a chromosome are different, as though our string of beads had no duplicate throughout its length. Moreover, each chromomere has a definite place or locus in the particular chromosome in which it belongs and is always found at that particular locus." Babcock and Clausen.

Such modern studies indicate that these microscopic chromosomes are very complex and contain units that may be responsible for specific characters. Every time the cell divides, there is an increase in the amount of chromatin material. It grows just as other parts of a cell grow. Were it not for this growth in the chromatin, it would be inconceivable how such a small amount of substance could be responsible for transmitting the parental characters to offspring. This relation is emphasized by the estimate of Parker, who states that the chromosomes in the human ovum weigh about 0.000004 mg. This makes the weight of the hereditary determining material to the average weight of a man as 1 to 16,250,000,000,000.

In this brief review of the nature of the germ cells and the structure of the chromosomes emphasis is placed on the independence of these parts. The germ cells do not participate in the formation of the soma but do give rise to germ cells that never fuse into tissues. The chromosomes are in pairs, in each of which one member is derived from each parent. Each chromosome is in turn composed of a large number of chromomeres which are believed to be constant in character. These are what some writers call the genes, determiners or factors in inheritance while others hold that the genes are very much smaller and are in themselves complex chemical bodies. During maturation of the germ cells of both male and female, there is an accurate distribution of the chromosomes so that the ripened ovum or sperm contains the haploid number of chromosomes. In fertilization the species number of chromosomes is reëstablished and the zygote has the diploid number of chromosomes. With these terms in mind we will examine the Mendelian interpretation of heredity.

Mendelism.—The Augustine monk, Johann Gregor Mendel, published in 1866 the results of his studies on the pedigree crossing of varieties of the edible peas in which he announced what many regard as one of the greatest of biological discoveries. Two illustrations will serve to introduce us to this method of explaining heredity. The common garden flower, four o'clock, shown in Plate II, produces a

white and red flower. When the pollen from the white-flowered plant is placed on the pistil of the red-flowered plant or the reciprocal cross is made and the seeds are planted, the flowers will be neither

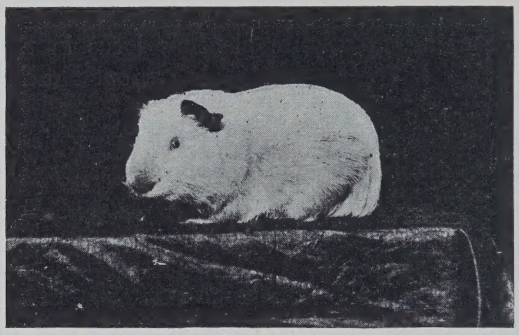


FIG. 165.—An albino male guinea-pig, father of the black young shown in Fig. 166. (After Castle.)

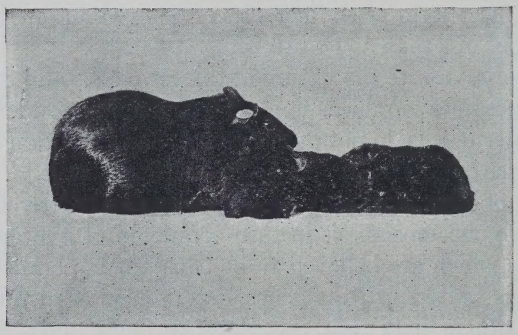


FIG. 166.—A female guinea-pig and her young sired by the albino in Fig. 165. (After Castle.)

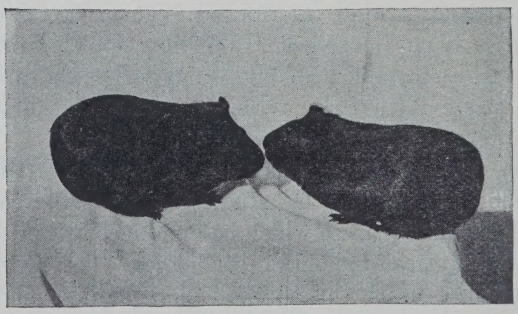
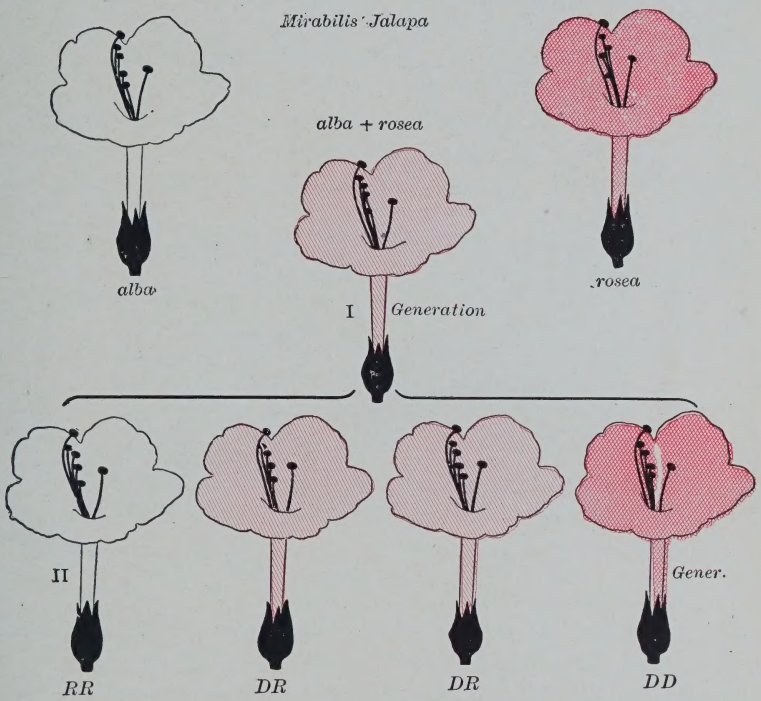


FIG. 167.—Two of the grown-up young of the litter shown in Fig. 166.

PLATE II


Mirabilis Jalapa
alba + rosea
alba
rosea
I Generation
II
RR
DR
DR
DD
Gener.

red nor white but pink. This is known as the hybrid generation I or first filial (F). When the pink hybrid flower of generation I is self-fertilized, the resulting flowers are white, pink and red. The number of white and red will be the same and together equal the number of the pink flowers or we may say that the colors are inherited according to the formula of 1:2:1. A similar idea is expressed in the experimental crossings of guinea-pigs by Prof. Castle. A white and black guinea-pig are crossed and the hybrid generation I is all black, Figs. 165, 166. In this instance the black hair color only is present. The white color is not lost as subsequent crossing of these hybrids proves. If the two hybrids shown in Fig. 167 are mated, the offspring will be white and black in the ratio of 3 black to 1 white, or the formula 3:1 applies. Certain terms are used to express these facts. When one character such as black hair color prevailed in the black hybrid,

FIG. 168.—A group of four young produced by the pair in Fig. 167. Note the reappearance of the white in a one-fourth ratio.

Mendel called that character *dominant* and the white hair color that was apparently suppressed, *recessive.* The complete dominance which Mendel observed in his pea experiments does not always occur as is shown for the four o'clock where the pink color is intermediate between the two parents but yet in the next hybrid generation the original white and red reappear as in Mendelian inheritance. This is known as the *law of dominance,* complete in the guinea-pig cross just described and incomplete for the four o'clock. In the second hybrid generation the white hair color of the guinea-pig and the white and red color of the four o'clock reappeared as in the grandparents. These colors are designated hereditary characters which were passed from parent to offspring without being modified during the time that they were in the germ cells of the hybrid of generation I. These characters did not fuse with other color characters. This is known as

the *law of segregation or the purity of the germ cells, i. e.,* "the determiners for contrasting unit characters are not carried together in the same germ-cell." The third conclusion that we may draw from these illustrations is that an organism is made up of many single characters each of which is transferred from parent to offspring essentially as a unit and this is the law of *unit characters.* In both of these experiments, the parents were alike except for one unit character and for that reason are termed *monohybrids.*

In Fig. 169 is presented a scheme to show what the effect will be in a monohybrid when the germ cells have dominant and recessive characters in different proportions.

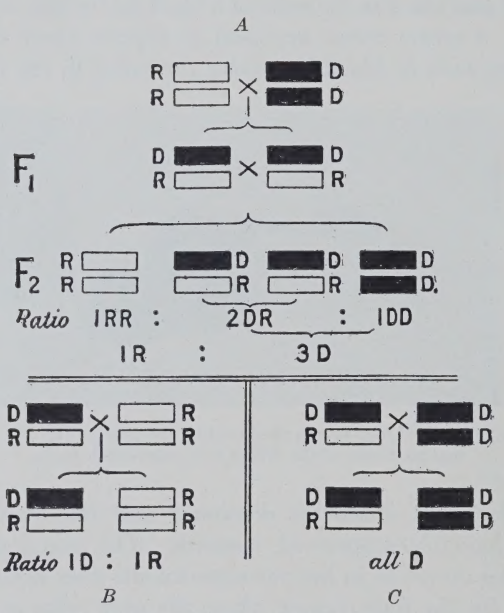


FIG. 169.—Schema of Mendel's law for a single pair of "antagonistic" properties. *A*, the results of hybridization of a pure dominant (*D*) with a pure recessive (*R*) form; *B*, the results of crossing a hybrid with a recessive form: 50 per cent. of progeny pure recessive, 50 per cent. hybrid (but apparently dominant); *C*, the result of crossing a hybrid with a dominant form; all apparently dominant (but 50 per cent. pure, 50 hybrid). (Bateson.)

Dihybrids.—The dihybrids are similar to the monohybrids except that there are two unit characters in each which become interchanged in crossing. Mendel showed how this more complicated inheritance works in his crossing of garden peas. The characters selected were *smoothness,* S, or *wrinkledness,* w, of the cotyledon and *yellow color* Y,

and *green*, g, as in Fig. 170. These four characters behave in a regular manner toward each other. S is dominant over w, and Y is dominant over g. When smooth-yellow, SY, and wrinkled-green, wg, are crossed, all of the generation I, hybrids have cotyledons that are smooth-yellow with wrinkled-greeness recessive. If the hybrids of this first generation are now crossed, there will be 16 possible

Eggs ♀ / ♂ Sperms	Sg	wY	SY	wg
Sg	Sg Sg Smooth green	wY Sg Smooth Yellow	SY Sg Smooth Yellow	wg Sg Smooth green
wY	Sg wY Smooth Yellow	wY wY wrinkled Yellow	SY wY Smooth Yellow	wg wY wrinkled Yellow
SY	Sg SY Smooth Yellow	wY SY Smooth Yellow	SY SY Smooth Yellow	wg SY Smooth Yellow
wg	Sg wg Smooth green	wY wg wrinkled Yellow	SY wg Smooth Yellow	wg wg wrinkled green

FIG. 170.—Diagram to show the possible combinations in a dihybrid. Large letters are dominant characters and the small letters are recessive. *S*, smooth cotyledon; *W*, wrinkled cotyledon; *Y*, yellow color of cotyledon; *G*, green color of cotyledon.

combinations because the male and female germ cells contain not only SY and wg, but also sg and wg. This is due to the way these unit characters segregate in maturation. Study the detailed possible 16 combinations from Fig. 170. The formula which expresses the ratio of a typical dihybrid is 9SY : 3Sg : 3wY : wg. We will not attempt in this elementary book to carry the Mendelian analysis

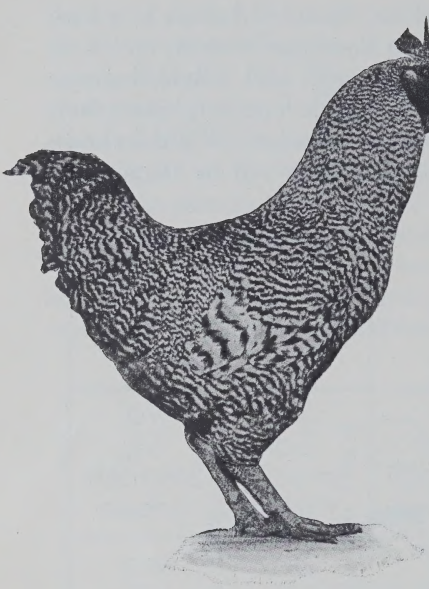


FIG. 171.—Pure bred barred Plymouth Rock. ♂

FIG. 172.—Pure bred Cornish Indian game. ♀

If one mates the cross-barred Plymouth Rocks ♂ × Cornish Indian game ♀ he gets only barred birds. (Pearl and Surface.)

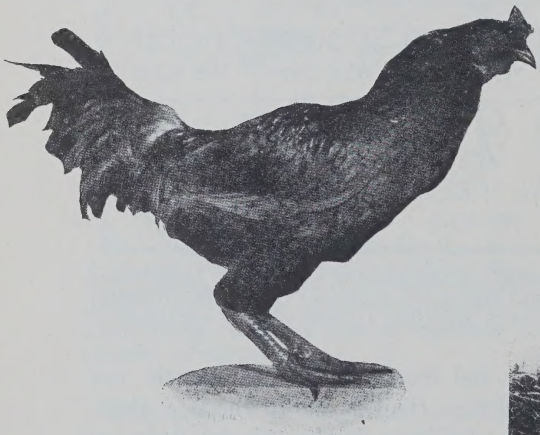


FIG. 173.—Pure bred Cornish Indian game. ♂

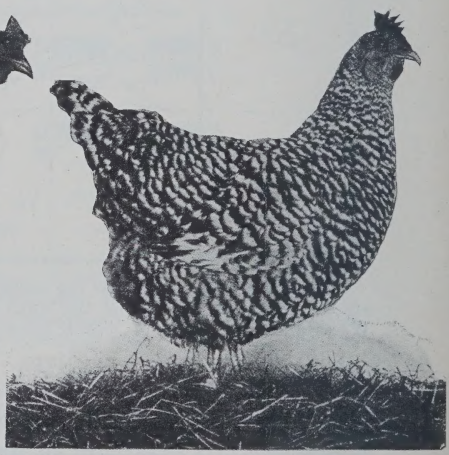


FIG. 174.—Pure bred barred Plymouth Rock. ♀

If one mates Cornish Indian game ♂ × barred Plymouth Rock, all the male offspring will be barred and the female will be black. (Pearl and Surface.)

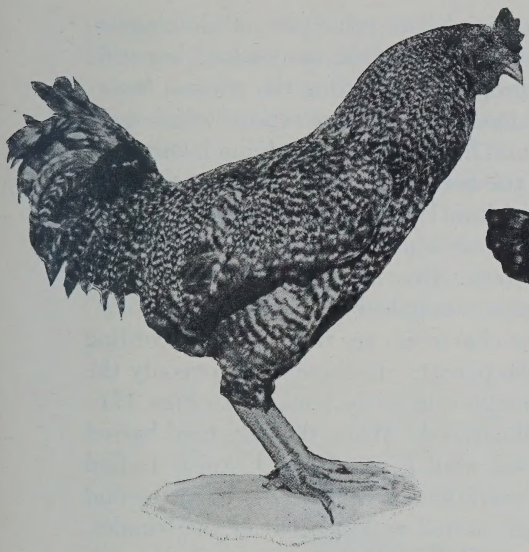


FIG. 175.—Barred F_1 hybrid ♂.

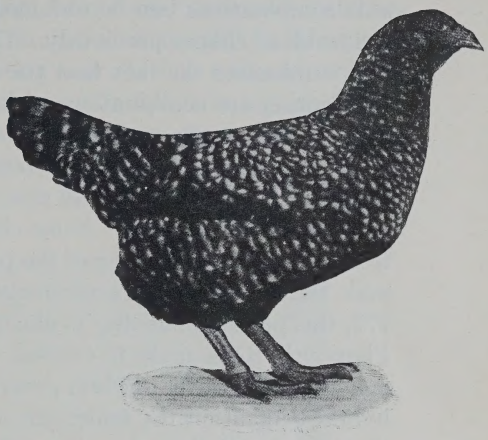


FIG. 176.—Barred F_1 hybrid ♀.

FIG. 177.—Non-barred (solid black) F_1 hybrid. ♀.

FIGS. 171 to 177 show that barring of the feathers is inherited in a sex-limited fashion. The barred pattern is inherited as a unit character and there is no evidence of a blended inheritance of degrees of intensity of pigmentation. No more striking evidence of the segregation and particulate behavior of characters as units in inheritance can be found anywhere. (Pearl and Surface.)

further. Utilizing the three Mendelian principles of dominance, segregation and unit characters, man is able to conduct scientific experiments in breeding. By properly controlling the crosses, favorable combinations can be obtained in a few generations which were the result of chance previously. This method of studying inheritance also emphasizes the fact that the hereditary differences that appear in offspring are combinations of unit characters that *were present in the parents,* but are combined in such a manner as to give the impression that they are new characters. One more phase of Mendelian inheritance will be presented, *i. e.*, sex-linked inheritance.

Sex-linked Inheritance.—Some characters are transmitted according to their relation to the sex of the parent. In these instances only the male transmits the character in question to the female. In Figs. 171–177, this phase of heredity is illustrated. When the pure bred barred Plymouth Rock male is crossed with a pure bred Cornish Indian game female, the first hybrid generation are all barred. In the second hybrid generation the males are barred and one-half of the females, the second half of the females are black. But when the male Cornish Indian game is crossed with the barred Plymouth Rock female, the females are all black but the males are barred. When the second hybrid generation of this cross are bred, barred and black birds occur in both sexes. There are various phases of sex-linked inheritance in different animals.

Blended and Mosaic Inheritance.—One of the commonest forms of blended inheritance is in the crossing between a white person and an negro. The offspring have a skin color that is unlike either parent but is a distinct blend. Skin color is not due to a single character as there are at least three pigments, red, yellow, and black in the skin of both white and black persons so that the problem is not as simple as the crossing of white and black guinea-pigs.

Sometimes the offspring exhibits both of the characters of the parents without the exclusion of either or a blending. Fig. 178 shows white and black colored feathers as distinctive as in the parents. Such a form of inheritance is known as mosaic.

Mutations.—The Dutch botanist, Hugo De Vries of Holland, made an intensive study of Lamarck's evening-primrose in 1886 and the years following. "This stately plant showed the long-sought peculiarity of producing a number of new species every year." These new species showed characters which were lacking in the parent plant and which did not revert to the parent type when self-fertilized but bred true to their new type. Recent experiments have thrown

some doubt on De Vries conclusions as the plant that he selected for his study is now regarded as a hybrid that breaks up into several forms that can be recombined by crossings. But other investigators, especially Morgan and his associates, have found numerous instances of mutations in the fruit-fly. A mutation is usually an abrupt or marked change occurring in offspring and which is not a recombination of parental characters. The change takes place in one generation and not by the slow accumulation of minute variations through many generations. Such sudden changes indicate that the orderly recombinations in the chromosomes have been modified, or technically

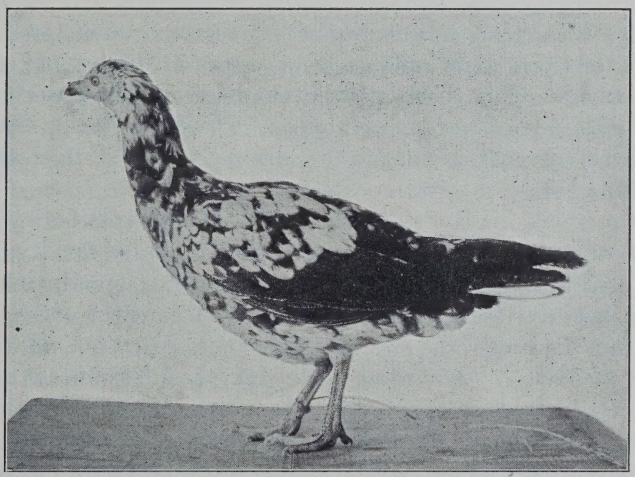


FIG. 178.—Hybrid fowl which is a cross between guinea hen and game-cock, showing in an interesting manner the distinctive color of both parents. This is a form of Mosaic inheritance. (Bred and photographed by Dr. Raymond Pearl.)

phrased, the genes have changed, Castle says that this conception of changed genes may be summed up in the statement that such changes come or go suddenly in their entirety and cannot, so far as we know, be influenced by selective or any other controllable process. Hence, we may call changes in genes "mutations." We do not know the cause of mutations.

Galton's Law of Heredity.—Francis Galton was one of the first men to introduce scientific methods into the study of variation and heredity. In all organisms that reproduce by the sexual or cross-fertilization plan, the offspring has a bi-parental inheritance. From our study of the germ cells and their part in reproduction, it is obvious that the

germ cells of the father are made up of hereditary factors from his two parents and the germ cells of the mother contain chromosomes that are derived from her two parents. This is expressed in the following table where the idea of grandparents and great-great-grandparents who each had parents soon gives an exceedingly large number of ancestors. It is customary to allow three generations to a century.

Generations.	Ancestors.
1	2
5	32
10 (time of Mayflower)	1,024
15	32,768
20	1,048,576

If this theoretical ratio were correct then one man today would involve the existence of millions of ancestors at the beginning of the Christian era. This absurd calculation does not take into consideration the close relationships in families. Davenport holds that those of English descent are not more distantly related than thirtieth cousins and most of them much closer.

Galton states his law as follows: The two parents between them contribute on the average one-half of each inherited faculty, each of them contributing one-quarter of it. The four grandparents contribute between them one-quarter, or each of them one-sixteenth; and so on, the sum of the series $\frac{1}{2} + \frac{1}{4} + \frac{1}{8} + \frac{1}{16}$, etc., being equal to 1, as it should be. "According to this law, the inheritance is not dual, but through the parents it is multiple and the contributions made by the grandparents, etc., is definite, diminishing as indicated. When this law is applied to individuals many exceptions follow but it should be remembered that this is a statistical method for studying a large amount of data and when sufficient data are included, the results are close approximations to the general idea although the exact fractions have been modified by Pearson. The main difficulty in applying this law is that most organic factors are not subject to such exact measurements and where blended or recessive characters are studied several generations must be studied. Some hold that Mendelism renders impossible Galton's law.

Acquired Characters.—We must make a clear distinction between the general term, heredity and acquired characters. Whenever one is able to trace the origin of a character to the germ cells, then it is said to be inherited. Such characters reappear generation after generation and can usually be analyzed and their behavior in the future predicted. In contrast we define acquired characters as those

whose causes are to be traced to the environment. A number of scientists have tried various forms of mutilation such as removing for several generations the tail of the mouse to see if this injury would eventually affect the germ cells and a shorter tail would result. For many centuries the Chinese have bound the feet of their women but this did not result in modifying the feet of the Chinese babies who continue to be born with normal feet. During the past ten years a number of careful experiments have been made in an attempt to shift a specific environmental factor to the germ plasm and have the result appear in successive generations. Stockard subjected guinea-pigs to alcohol and Guyer has produced eye defects in rabbits.

The more one studies the general problem of development, the more it becomes evident that there is a very delicate balance in the growing organism. First one organ appears, then another. When some environmental factor tends to temporarily inhibit the natural rhythm of growth, certain unusual relations or defects arise. The eye defects in rabbits, which Guyer has observed to re-occur for at least eight generations, Stockard holds are to be explained as due to deficiency in development.

"It may further be appreciated that when the eyes are structurally deformed or deficient in an individual there is a likelihood that other organs and parts have also suffered from the same arresting cause. This is well shown in many cases by the experimentally treated embryos, the alcohol treated-guinea-pigs and the roentgen-ray mice of Bagg and Little. Conversely, it is probably more often true that when developmental arrests are present in various body organs, the eyes of such an individual are also structurally deficient."

The most conclusive experiments against the influence of the body on the germ cells is furnished by the brilliant experiments of Castle and Phillips. Crosses between pure black guinea-pigs and pure white have already been described and the behavior of these two colors is well understood so that any modification is easily detected. If the soma cells can produce modifications in the germ cells, then the transferring of the germ cells from one animal to another would enable a different set of soma cells to nourish them. This is the experiment that Castle and Phillips were able to carry out, the results of which are indicated in Figs. 179–184. In this test, then, the soma cells did not modify the hereditary characteristics of the germ cells.

If the extreme position advocated by those who claim that the germplasm is the exclusive source of variation is accepted, then there can be no progressive variation, for the range of all such variation

is limited by the combination of characters derived from parents, grandparents, etc. When one takes a broad survey of organic structures, progressive modification is one of the most apparent facts, as the skull and many other parts of vertebrates clearly indicate.

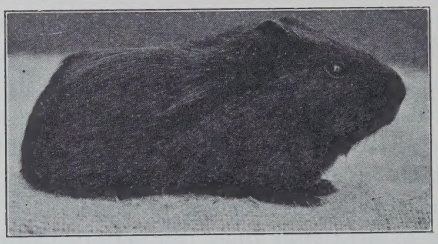


FIG. 179

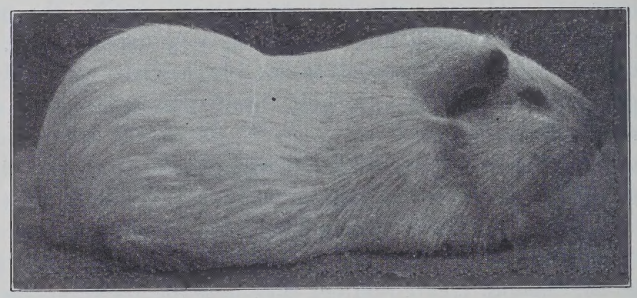


FIG. 180

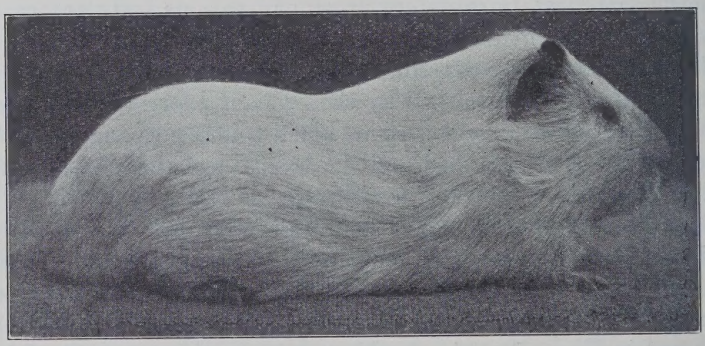


FIG. 181

FIGS. 179, 180 and 181.—Fig. 179, a young black guinea-pig, about three weeks old. Ovaries taken from an animal like this were transplanted into the albino shown in Fig. 180. Fig. 180, an albino female guinea-pig. Its ovaries were removed and in their place were introduced ovaries from a black guinea-pig (Fig. 179). Fig. 181, an albino male guinea-pig, which was mated with the albino shown in Fig. 179. (Description and figures from W. E. Castle.)

The germplasm advocates of variation hold that mutation, the combination of germplasm factors which result in producing a distinctly different individual by changing many characters at once, explains most of these differences.

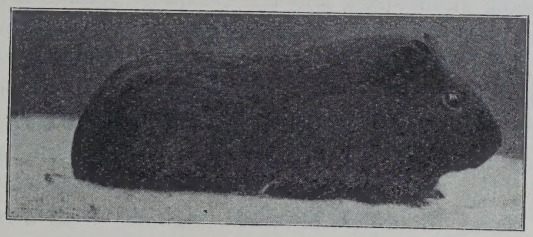


FIG. 182

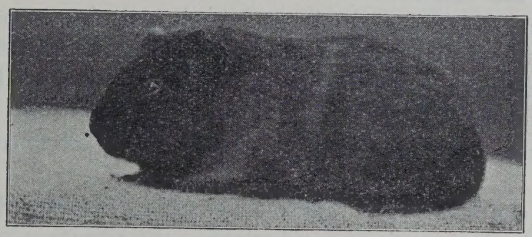


FIG. 183

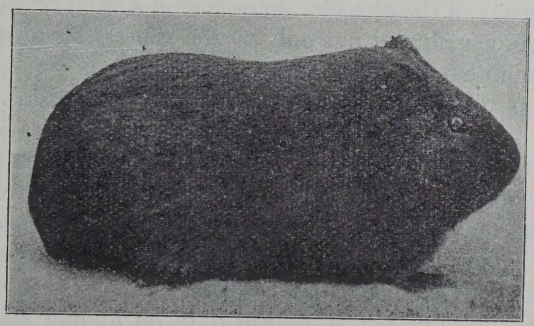


FIG. 184

FIGS. 182, 183 and 184 are pictures of three living guinea-pigs, all of which were produced by the pair of albinos in Figs. 180 and 181. From evidence such as this it is concluded that the inheritance cannot be affected by modifications of the body of the parent, not even when the body is completely changed, since the body so far as heredity is concerned is merely a container of the reproductive cells. To modify the inheritance we must modify the reproductive cells. (Description and figures from W. E. Castle.)

On the other hand Castle points out that the color of the hair of the domestic varieties of cavies is more distinct and clear than in wild forms. "For example it is possible by crosses to obtain from wild cavies the retrogressive varieties, black and yellow. But such synthetic blacks lack the full intensity of blackness found in our best strains of black guinea-pigs, and the synthetic yellows are apt to be either pale or muddy in yellowness, lacking the intensity and brilliancy of our best domestic varieties. It is impossible to escape the impression that our improved domestic varieties are not mere factorial recombinations derived from wild species, but that they have been forced up to a higher standard by repeated selection; that the breeder, for example, has first observed variation in intensity of blackness among his blacks (doubtless obtained originally from a retrogressive sport) and that by repeatedly selecting the blackest available individuals he has increased the blackness of the race. Thus it is no accident that the meat and milk and wool-producing capacity of our domestic animals far exceeds that of any wild ancestral species. The standard in each case has been raised and it has not been raised by a single lucky accident (the mutation view), but by a series of slow advances each impossible until a previous advance had been made."

Heredity and Man.—The same biological processes regulate human origin as obtain in animals and plants. Fertilization is necessary and the hereditary factors are parts of the chromosomes. Even a superficial study of the physical characters of a child reveal that both parents have contributed not only to the general form of the body, but to the minute features of the hand, hair or eyes.

Man is one of the most highly specialized organisms. This has resulted in a delicately balanced physiological organization. All of this has introduced a complexity into human inheritance that is very difficult to analyze. Society does not approve of controlled experimentation such as obtains in plants and animals. But man has been observed for many years, and the results are becoming better understood because of these statistical studies.

Galton began to collect statistical data on human inheritance as early as 1869; and his books on "Hereditary Genius," "English Men of Science," and "Inquiries into the Human Faculty," have become classics in the field of human inheritance. More recently defective human inheritance has been studied and the data on feeble mindedness, epilepsy and insanity has added considerably to our information about deficiency in human inheritance. These studies are best known

through the "Jukes Family" and the "Martin Kallikak Family" records.

The opposite phase of human inheritance is in the study of superior mental qualities. Here the records are equally interesting. Artists, musicians, Fellows of the Royal Society in London, English judges, famous scientists, the Edwards Family in America, Oxford scholars, and other superior groups have been studied and the number of descendants that show the superior parental qualities is very large. But as to the exact laws governing the inheritance of human mental qualities, as yet little is proved. Some of the recent writers believe that they are unit characters, but there is scarcely any one who holds that each quality is determined by a single germinal character and inherited according to the simple Mendelian law. Owing to the remarkable complexity of man, the possible germinal combinations are almost unlimited. Until we know a great deal more than we do at present, it is wise to be cautious in our generalizations concerning human inheritance. This in no way contradicts the statement that man is subject to biological laws. It simply means that our information is too incomplete at present for us to predict in detail human inheritance.

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CHAPTER XXII.

SOME THEORIES OF EVOLUTION.

From time to time men reflecting on the known facts of Nature and organic life in particular have attempted to explain the manner in which these relations have arisen. These men have been guided largely in their classification of the facts of life by the scientific method and have attempted to draw logical conclusions from these facts. Their next step has been to provide a suitable explanation of how the facts came to have their present relations to each other. These explanations are termed the hypotheses or theories about the origin, adaptation and development of organisms. There have been many attempts to solve this great problem and no one can be said to have been entirely successful. The men that formulated their explanation one hundred years ago did not have as many facts nor were their facts as well organized as they are now. Consequently their theories seem crude and incomplete.

From the time of Aristotle down through the dark ages to Erasmus Darwin (1731–1803) various men have tried to formulate the fundamental principles that explain the origin, adaptation and development of organisms by descent. The most successful of all of these earlier writers was Lamarck.

Lamarck's (1744–1829) life is the old, old story of a man of genius who lived far in advance of his age, and who died comparatively unappreciated and neglected. In this history of the development of the idea of evolution he is the most prominent figure between Aristotle and Charles Darwin. His treatise *Philosophie Zoölogique* shows: "First, the certainty that species vary under changing external influences; second, that there is a fundamental unity in the animal kingdom; third, that there is a progressive and perfecting development." To Lamarck is given the credit for having been the first to formulate a definite theory of evolution.

Lamarck is chiefly known for the four laws of evolution which Osborne translates as follows: (1) The Law of Growth. Life by its internal forces tends continuously to increase the volume of every body that possesses it, as well as to increase the size of all the parts of the body up to a limit which it brings about. (2) The Law of

Functional Reaction. The production of a new organ or part results from a new need or want, which continues to be felt, and from the new movement which the need initiates and continues. (3) The well-known Law of Use and Disuse. The development of organs and their force or power of action are always in direct relation to the employment of these organs. (4) Use Inheritance. All that has been acquired or altered in the organization of the individuals during their life is preserved by generations and transmitted to new individuals which proceed from those which have undergone these changes. Lamarck, like Erasmus Darwin, accepted spontaneous generation, for he held that Nature was always creating elemental plants and animals.

The fourth law of Lamarck is the one that has received the most criticism, as it is really fundamental to his whole conception of evolution, assuming as it does the inheritance of acquired characters (page 272). This law was accepted without question for a hundred years until Weismann challenged the supposed fact of the inheritance of acquired characters. A large literature has accumulated about this problem with many prominent scientists on each side of the controversy with the result that there has grown up a school of writers on organic evolution known as neo-Lamarckians, who defend in a modified form Lamarck's views; and an opposing school known as neo-Darwinians, who hold that Darwin's conceptions furnished the true explanation.

Much of the bitterness of this controversy has died down because it has come to be recognized that it is not so much a question of theory as of actual experiment. The really crucial tests revolve around experiments that deal directly with the germ cells. This is the reason why the experiments (page 273) of Castle are given so much importance. But there must be many more successful experiments before we can regard the question as proved.

The third law of Lamarck gives one a clear idea of the method of development of general bodily characters, such as bones, muscles, etc., but it does not explain how a protective coloration (Fig. 215), may have started. We thus have to make an exception to this general law and apply it only in a limited manner.

The questions and objections raised to the third and fourth laws of Lamarck give you some idea of the nature of the criticisms that many regard as valid against Lamarck. This in no way, however, detracts from the great credit that will always belong to him for having been the first to formulate a philosophic explanation of organic life.

Charles Robert Darwin (1809–1882), the great naturalist and author, by his interpretation of organic life as a result of his study, made a most notable contribution to our conception of evolution.

From 1831 to 1836 he acted as naturalist on H. M. S. *Beagle,* which made an extensive surveying expedition. During this time he thought

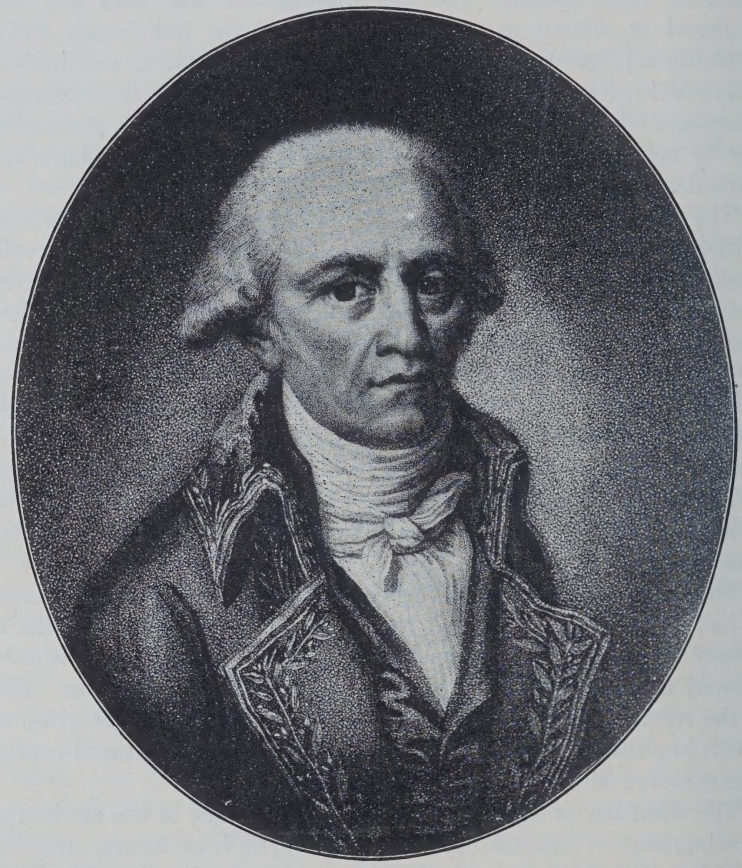

FIG. 185.—Lamarck (1744–1829). (From Locy's Biology and its Makers.)

and read about the collections of fossil and living forms made by the *Beagle,* and he says that it was "by far the most important event in my life, and has determined my whole career." On his return he published his observations in *A Naturalist's Voyage,* which is one of the most delightful records of a naturalist's travels ever produced.

Darwin owed a great deal to his predecessors, more than is generally believed, because a rather complete conception of evolution had already been reached, and some of the evidence stated. He

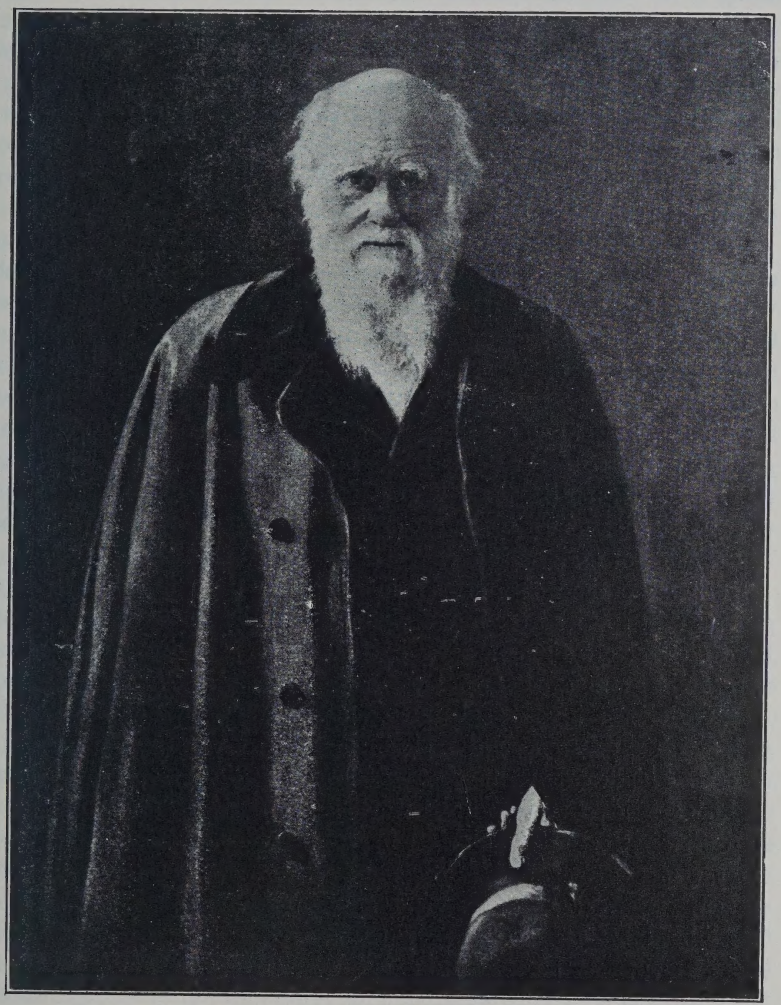

FIG. 186.—Charles Darwin (1809–1882). (From Locy's Biology and its Makers.)

was strongly influenced by reading Lyell's *Principles of Geology,* and later while studying domestic animals he read Malthus *On Population,* as a result of which "the idea of selection in a state of

nature first occurred to him as a result of the struggle for existence, or rather for life, between different individuals and species." Darwin's great contribution to evolution is the *Origin of Species* as a result of a struggle, utilizing variations and letting nature select, which is what is meant by the term "Natural Selection" or the "Survival of the Fittest." "Natural selection, then, is a theory which seeks to explain by natural causes the occurrence of every kind of adaptation which is to be met with in organic nature, on the assumption that adaptations of every kind have primary reference to the preservation of species, and therefore also, as a general rule, to the preservation of their constituent individuals."

Variation is the key-note to Darwinism, and one of the chief lines of research since his time has been to determine the causes of variation. Some idea of Darwin's notion in regard to variation is to be gained from the following: "It seems clear that organic beings must be exposed during several generations to new conditions to cause any great amount of variation, and that when the organism has once begun to vary, it generally continues varying for many generations. No case is on record of a variable organism ceasing to vary under cultivation. Our oldest cultivated plant, such as wheat, still yields new varieties; our oldest domesticated animals are still capable of rapid improvement or modification."

During the time of Lamarck and Darwin the opinion was very general that species were immutable and remained so unless changed by a distinct creation. Today it is regarded as a difficult problem to formulate a satisfactory definition of species. Darwin maintained that varieties arise through individual differences. "Hence I look at individual differences, though of small interest to the systematist, as of the highest importance to us, as being the first steps toward slight varieties as are hardly worth recording in natural history. And I look at varieties which are in any degree more strongly marked and permanent, as steps toward more strongly marked and permanent varieties; and at the latter as leading to subspecies." . . . "Again it may be asked, How is it that varieties which I have called incipient species, become ultimately converted into good and distinct species, which in most cases obviously differ from each other far more than do the varieties of the same species? How do these groups of species, which constitute what are called distinct genera, and which differ from each other more than do the species of the same genus, arise? All of these results follow from the struggle for life. Owing to this struggle, variations, however slight and from

whatever cause proceeding, if they be in any degree profitable to the individuals of a species, in their infinitely complex relations to other organic beings and to their physical conditions of life, will tend to the preservation of such individuals, and will generally be transmitted to the offspring. The offspring, also, will thus have a better chance of surviving, for, of the many individuals of any species which are periodically born, but a small number can survive. I have called this principle, by which each slight variation, if useful, is preserved, by the term Natural Selection, in order to mark its relation to man's power of selection. But the expression often used by Mr. Herbert Spencer of the Survival of the Fittest is more accurate and is sometimes equally convenient. We have seen that man by selection can certainly produce great results, and can adapt organic beings to his own uses, through the accumulations of slight but useful variations, given to him by the hand of Nature. But natural selection, as we shall hereafter see, is a power incessantly ready for action, and is as immeasurably superior to man's feeble efforts as the works of Nature are to those of art."

There has been considerable hysterical writing in regard to the brutality of the struggle for existence which has been read into and superimposed on Darwin's original conception. "I (Darwin) should premise that I use this term in a larger and metamorphical sense, including dependence of one being on another, and including (which is more important) not only the life of the individual but success in leaving progeny. Two canine animals, in time of dearth, may be truly said to struggle with each other which shall get food and live. But a plant in the edge of a desert is said to struggle for life against the drought, though more properly it should be said to be dependent on moisture. A plant which actually produces a thousand seeds of which only one can manage to come to maturity, may truly be said to struggle with the plants of the same and other kinds which already clothe the ground. The mistletoe is dependent on the apple and a few other trees, but can only in a far-fetched sense be said to struggle with these trees, for if too many of these parasites grow on the same tree, it languishes and dies. But several seedling mistletoes, growing close together in the same branch, may more truly be said to struggle with each other. As the mistletoe is disseminated by birds, its existence depends on them, and it may metaphorically be said to struggle with other fruit-bearing plants in tempting the birds to devour and thus disseminate its seeds. In these several senses, which pass into each other, I use for convenience' sake the general term 'Struggle for Existence.' "

In these extracts in Darwin's own words, we have his methods of interpreting changes in living things. Though he was one of the most abused men of the past century, he lived to see many turn

FIG. 187.—*Archæopteryx lithographica.* This interesting fossil, which has teeth, fingers and a tail similar to members of the Reptile group, has hind limbs and feathers characteristic of birds. Such fossils as *Archæopteryx* help to explain how some of the evolutionary transitions took place. (After Dames.)

to his views. At the close of the century *The Outlook* held a canvass of opinion as to the greatest book written from 1800 to 1900 and Darwin's *Origin of Species* received the largest number of votes as being the book that has had the greatest influence in molding the

thought of the century. This fact alone is sufficient to justify the claim that one cannot properly understand the intellectual development of the civilized world between 1850–1900 without reading the *Origin of Species*.

As to Darwin's theory of Natural Selection there has been from the first serious doubt that new species actually do arise through the accumulation of minute variations, for if Nature selects those forms

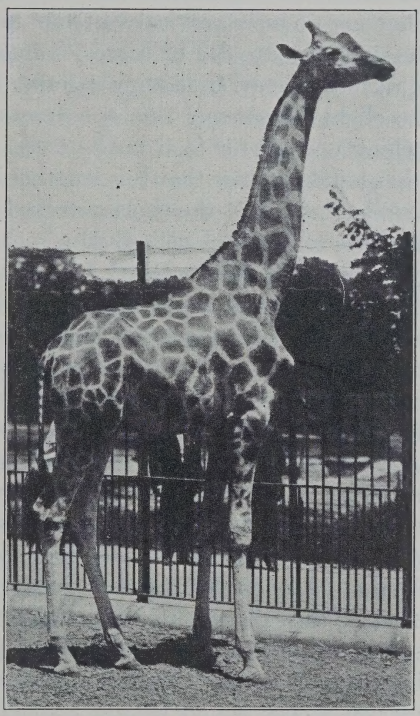

FIG. 188.—The long-necked giraffe. Courtesy of New York Zoölogical Society. (Photographed by E. N. Sanborn.)

of life that have a variation or group of variations then these variations must be of such a character that they are actually helpful. But most of Darwin's recorded variations are so minute that it is impossible to conceive how they could come under the influence of the selective process.

It is especially difficult to see how such minute variations would give rise to organs of extreme perfection and complexity such as the vertebrate eye. Even Darwin doubted that natural selection is

responsible for such a structure, for he says: "To suppose that the eye with all its inimitable contrivances for adjusting the focus to different distances, for admitting different amounts of light and for the correction of spherical and chromatic aberration, could have been formed by natural selection, seems, I freely confess, absurd in the highest degree."

The following illustration contrasts the difference between the views of Lamarck and Darwin: The giraffe is known to have a very long neck, although there are no more cervical vertebræ in the neck of the giraffe than in the neck of man, dog or horse. Lamarck argued that the giraffe's neck was lengthened by adding together from generation to generation the slight increments due to exercise (use) of each individual in reaching upward for food in the trees. Darwin's conception on the other hand assumes that this lengthening is due to the elimination in periods of stress of the shorter-necked individuals and the preservation of the longer-necked individuals that were able to live because they could secure the necessary food.

Darwin found it necessary to supplement his general theory of natural selection which did not explain the many differences between the sexes of animals that pair. To account for these, he formulated what is known as the theory of *Sexual Selection.* "This form of selection depends, not on a struggle for existence in relation to other organic beings or to external conditions, but on a struggle between individuals of one sex, generally the males, for the possession of the other sex. The result is not death to the unsuccessful competitor, but few or no offspring. Sexual selection is, therefore, less rigorous than natural selection. Generally the most vigorous males, those which are best fitted for their place in nature, will leave most progeny. But in many cases victory depends, not so much on general vigor, as on having special weapons confined to the male sex (Fig. 204). A hornless stag or spurless cock would have a poor chance of leaving numerous offspring. Sexual selection, by always allowing the victor to breed, might surely give indomitable courage, length to the spur, and strength to the wing to strike in the spurred leg in nearly the same manner as the brutal cock-fighter by the careful selection of his best cocks." This theory is fully discussed by Darwin in Part II of *Descent of Man.*

So many exceptions have been found to Darwin's contention, together with the necessary assumptions that a high degree of esthetic taste exists in many of the females, that most biologists have rejected his theory of sexual selection. Reference is made to this theory of

Darwin's because it serves admirably as an illustration of the important fact that there is not at present any completely satisfactory explanation of the origin of secondary sexual characters and sexual dimorphism.

Orthogenesis.—This is the name for the explanation that various authors have given to variation that appears to proceed in definite directions. Darwin's conception of variations is that they are scattered or fortuitous, and that natural selection takes advantage of them in whatever form they arise. Eimer was the first writer to express this interpretation of variation. Cope and Whitman have expressed their conviction that orthogenesis was an important factor in explaining the progressive changes in organisms. Students of palaeontology have been strongly impressed with this explanation as they have studied the history of the horse, camel and elephant in vertebrates; and molluscs among invertebrates. Osborn writes after thirty-three years of study that he is convinced that the origin of new characters is invariably orthogenic. "Even by trying to keep an absolutely open eye and mind, entirely uninfluenced by any theory, or preconception, or opinion, I have been unable to find a single exception among these many different kinds of mammals to the observations made on the Primates in 1888 and 1889; not a single new organ is observed to arise fortuitously or indefinitely; it always arises gradually, continuously, and adaptively from its minute shadowy beginnings. This continuous reciprocal, mechanical co-adaptation seems to be an established fact in evolution, and is established most strongly where explanation or search for causes seems to be most difficult.

"I am not enthusiastic about the adoption of the term orthogenesis, admirably significant as it is in its Greek derivation, (1) because Eimer connected it with Lamarck's and Buffon's principles of inheritance of acquired modifications, and (2) because it does injustice to the first great observer of direct adaptive origins in Nature, namely, the German paleontologist Wilhelm Heinrich Waagen, whose observations in 1869 laid the foundation for all subsequent work both among the invertebrates and the vertebrates. To the best of my knowledge *he was the first naturalist to observe how new species actually arise in Nature.*"—Henry Fairfield Osborn.

The special explanation of variations which orthogenesis offers, the different types of criticism against the theory of Lamarck and the theory of Darwin should not obscure in your mind the fact of evolution itself. There is very general agreement among the scientists of the world that modern animals and plants have been derived by

modifications from preëxisting animals and plants. The mere fact that one or several men have not been able to state completely just how this descent took place should not lead you into that confused state of thinking that there has been no descent. Light traveling from stellar space may not reach our earth until more than a thousand years after it started earthward. The star which gave off these light-rays may have gone out of existence many years ago, even before America was discovered; so far as we can prove we shall not know until certain light-rays cease to reach us. What keeps them going? Shall we deny their existence because we cannot explain all of the conditions governing them? This familiar illustration helps us to realize that our understanding of many great problems is still far from complete. Darwin's conception of the part played by natural selection still remains as the most important explanation that has been offered. We may accept for the time being Osborn's conclusion, "We know to some extent how plants and animals and man evolve; we do not know why they evolve."

Some have written that Darwinism leads to atheism but Darwin was reverent in his attitude toward Nature and acknowledged the part played by the Creator.

"It is interesting to contemplate a tangled bank, clothed with many plants of many kinds, with birds singing on the bushes, with various insects flitting about, and with worms crawling through the damp earth, and to reflect that these elaborately constructed forms, so different from each other, and dependent upon each other in so complex a manner, have all been produced by laws acting around us. These laws, taken in the largest sense, being Growth with Reproduction; Inheritance which is almost implied by reproduction, Variability from the indirect and direct action of the conditions of life, and from use and disuse: a Ratio of Increase so high as to lead to a Struggle for Life, and as a consequence to Natural Selection, entailing Divergence of Character and Extinction of less-improved forms. Thus, from the war of Nature, from famine and death, the most exalted object which we are capable of conceiving, namely, the production of the higher animals, directly follows. There is a grandeur in this view of life, with its several powers, having been originally breathed by the Creator into a few forms or into one; and that, while this planet has gone cycling on according to the fixed law of gravity, from so simple a beginning endless forms most beautiful and most wonderful have been, and are being evolved."—Darwin.

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LOCY: Biology and Its Makers.
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OSBORN: From the Greeks to Darwin, Origin and Evolution of Life.
THOMPSON: Evolution, Darwinism and Human Life.
WALLACE: Darwinism.

CHAPTER XXIII.

EVOLUTION AND THE STUDY OF FOSSILS.

In all definitions of organic evolution, there is emphasized the continuity of life. Nowhere can this conception be more severely tested than in the study of fossils because of the enormous amount of time that has elapsed since the earlier rocks were laid down and the profound changes that have taken place in the rocks themselves as great inland seas were transformed into dry land and mountain ranges rose from the level plains.

Huxley's very apt definition "Fossils are only animals and plants which have been dead rather longer than those which died yesterday," expresses the modern conception.

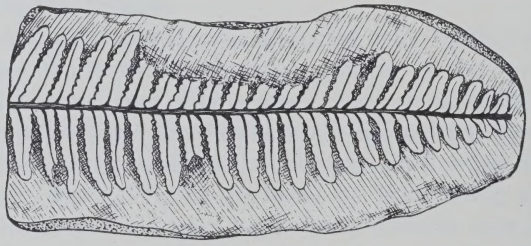

Fig. 189.—Fossil fern from the coal measures (carboniferous period). Do you know any modern ferns that look like this species?

Fossil remains of organic life were observed by the ancient Greeks, some of whom believed that the fossils were an indication that the sea formerly convered the earth, but their real significance was not comprehended. It was not until the sixteenth century that the true nature of fossils was surmised. The Italian Leonardo da Vinci has the distinction of first announcing that fossils were the remains of plants and animals that had once been alive but at an earlier period. In 1669, Steno argued that similar effects are due to like causes and that the conditions that would produce structures like those existing in living animals and plants could have been formed only in organic beings, hence fossils must be the remains of living things.

The next step consisted in comparing fossil remains with living forms which resulted in the conclusion that many fossils belonged to extinct races of animals and plants. As such comparisons were being made it was observed that a given kind of fossil usually occurred in the same strata of rock, which was of great assistance in the identification of the age of rocks in disconnected regions.

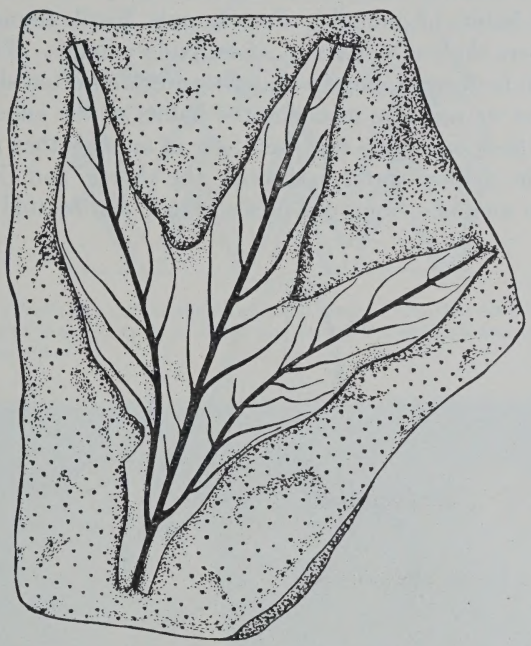

FIG. 190.—Fossil leaf from a sassafras tree that was common in the cretaceous period.

Scientists have agreed that all remains or traces of plants and animals that have lived before the present geological period, and that have been preserved in the rocks, are to be regarded as fossils. These remains usually become petrified, *i. e.*, various mineral substances take the place of the organic matter. On the other hand, we have carcasses of mammoths entombed in the frozen mud-cliffs of Siberia and insects caught in the amber of gum-trees that are just as truly fossils. Even tracks in the mud, the imprint of a leaf or a shell come under this definition of a fossil.

Animals possessing skeletons in some form, such as either the external skeleton of a crayfish or the internal skeleton of a frog, would be

more apt to be preserved as fossils than jelly-fish or earthworms. The life in the seas had a better chance for preservation than the life on land, because land animals would not be covered over before they decayed or were eaten except when caught in a peat bog or morass. This is the reason why we know so much less about the life on land as compared with ancient aquatic life.

The kind of rocks in which fossils are found helps us to reconstruct many of the habits of animals. For example, fossils found in sandstone rock were shallow water and shore living animals. These rocks are known to be formed only in shallow water and often show ripple marks. Thus we are able to define the habits of the animals found as fossils in these sandstone rocks as those of animals that must have been living in shallow water and along the shores, and the kind of food and the methods employed in securing it can be told with confidence.

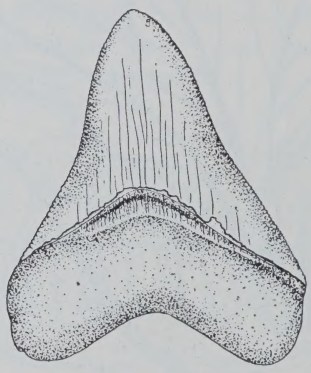

FIG. 191.—Tooth of a fossil shark (*Charcharodon megalodon*) of the tertiary period. Compare the parts of this tooth with those shown in Fig. 192.

On the other hand, fossils found in hard limestone rocks tell another story because we are just as certain that such rocks are formed in deep water, possibly in the dark abysses of the ocean. The organic remains in such rocks were mostly free swimmers in the ocean (pelagic) and sank to the bottom after death. Their habits were distinct from those of the animals that were preserved in the sandstone strata.

It is not common for the entire skeleton to be preserved in the same place. Tides and waves helped to scatter the many parts over a wide area so that but a few bones are usually found together. Then too the subsequent changes that have taken place in the rocks themselves,

especially the large amount of erosion, have often destroyed portions of the rock strata and its contained fossils. The result is that paleontologists have not been able to secure complete records even of individual animals, to say nothing of finding the different species of animals and plants that once lived on land and in the water of prehistoric time.

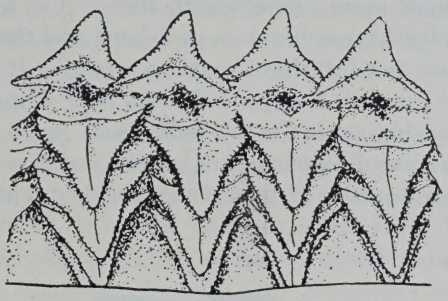

FIG. 192.—Teeth of a recent shark—natural size. Note that they are arranged in successive rows. As soon as those at the top wear down or break the ones in the next row take their place.

FIG. 193.—*Venus mercenaria* fossil on the left and recent on the right. This animal has undergone practically no change during all of modern geologic time.

The most commonly found parts are the teeth and vertebræ of vertebrates while imprints of the shells of molluscs and brachoipods are more frequently encountered among the invertebrates. In one locality a given form of life prevails in the rocks while in another an entirely different species of fossil is more numerous.

Persistence of Primitive Types.—The study of the older rocks reveals the remains of a number of animals that have persisted for millions of years without undergoing important modifications. These animals are mostly of a primitive type. When one tries to compare them with modern animals, it is difficult because many changes have taken place in most of them. These modern forms are mostly more highly differentiated and show more adaptive structures. The relatives of these persistent primitive types became specialized and then extinct. The Bowfin, Fig. 194, is a fish that should be a fossil. It cannot be compared with modern fish because it has no near living relatives. Its next of kin became extinct some millions of years ago during the Mesozoic. The lizard Sphenodon (Hatteria) of New Zealand, is the only living representative of the extinct "beaked reptiles," the study of which is of great value to those who wish to understand these ancient, extinct animals.

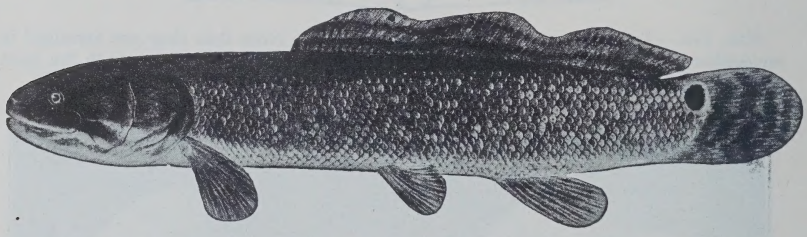

FIG. 194.—Bowfin, a fish that should be a fossil. The bowfin cannot be compared with modern fish because it has no near relatives in this country or in any part of the world. Its next of kin became extinct some millions of years ago during the Mesozoic. The king-crab Limulus, the brachiopod Lingula and the plants known as scouring rushes, the Equisetæ, are additional organisms which have persisted for millions of years without undergoing much modification. It is only by a study of fossils that we have come to know anything about the family history of these several organisms.

The brachiopod, *lingula*, is even older than these just mentioned, dating to the Ordovician geological period; while the king-crab, *Limulus*, can boast almost as extensive a genealogy. The same is true for plants as all realize who have observed the scouring rushes, Equisetæ, and tried to relate them to modern forms.

Number of Fossils.—Schuchert estimates that there must have been living during the entire Jurassic period something like 31,000,000 kinds of animals. Paleontologists have described more than 15,000 Jurassic forms. The great variety of the extinct life record is thus forcibly brought to our attention, and we learn from these estimates that for each kind of animal preserved in the rocks more than 2000 other kinds are missing from the geological record.

Evolution of the Horse.—Geological history is divided into great periods of time. The last and shortest is the age of man or the Quarternary. In the early part of this period, wild species of horses were to be found in every continent except Australia. Fossil remains of these horses have been found in the rocks of the United States, Mexico, Brazil, Europe, Asia and Africa. All of these prehistoric horses in North and South America became extinct. In Europe some of the prehistoric horses were domesticated by man as proved by the carvings and drawings found in the caves belonging to the stone age.

These Quarternary horses have skeletons similar in nearly all details to modern horses. The teeth, and legs in particular, are nearly identical. What is known about the origin of these highly specialized organs?

The earliest known ancestors of the horse were small animals not larger than the domestic cat, with four complete toes on each fore-foot and three on each hind-foot. Commencing with the Hyracotherium, twelve stages have been recognized from as many successive formations, showing the gradual evolution of the race into its modern form, and each stage is characteristic of its particular geological horizon. Some of the stages have been found in several parts of the world, but by far the most complete and best known series comes from the Tertiary Badlands of the western United States. Besides the main line of descent which led into the modern horses, asses and zebras, there were several collateral branches which have left no descendants.

The Table, Fig. 195, summarizes the important changes that have occurred in the extinct species of horses. There were first the small four-toed horses, some no larger than a cat, they were followed by the small three-toed horses; and these in turn by the large three-toed species. The next important change was the shortening of the two lateral toes, leaving a one-toed horse.

Along with the disappearance of the side toes in the evolution of the horse there is a considerable increase in the proportionate length of the limbs, and especially of the lower part of the leg and foot. The surfaces of the joints, at first more or less of the ball-and-socket kind which allows free motion of the limb in all directions, become keeled and grooved like a pulley-wheel, permitting free motion forward and backward, but limiting the motion in all other directions

[1] Taken from The Evolution of the Horse, by W. D. Matthew and S. H. Chubb, American Museum of Natural History.

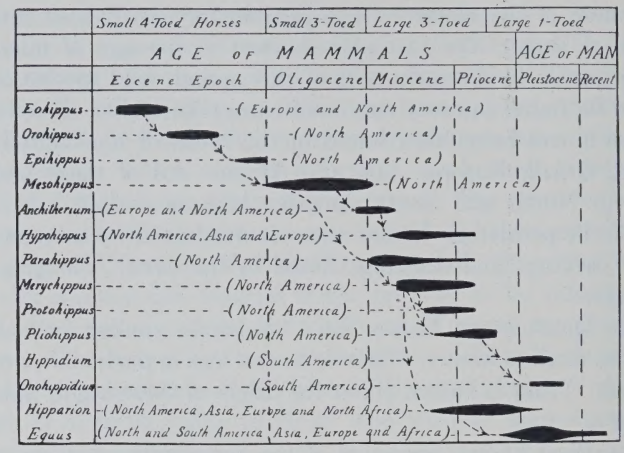

FIG. 195.—Geological and geographical range of ancestors of the horse. The position and length of the heavy black lines show the occurrence and range of each genus in the successive geological epochs, while the thickness of the lines indicates relative abundance. The dotted connecting lines with arrows indicate the genealogy. (Matthew and Chubb.)

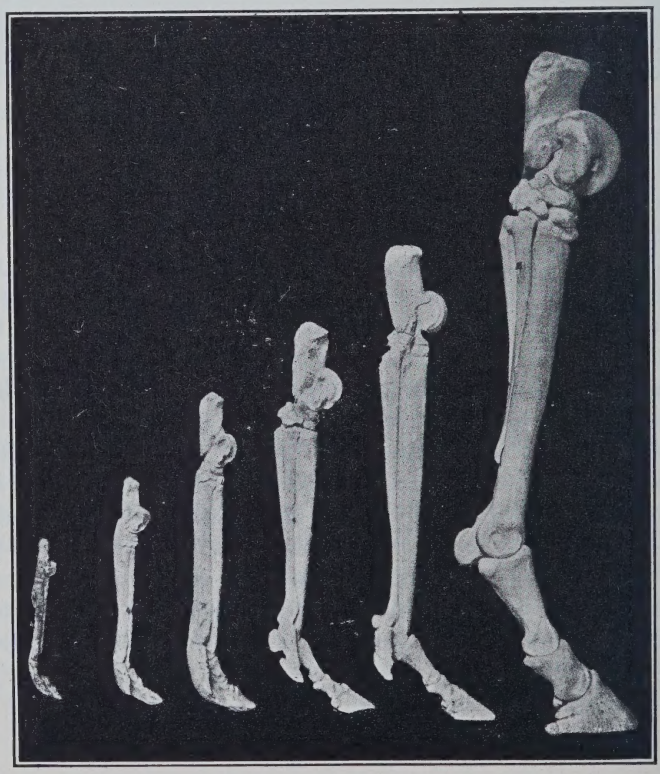

FIG. 196.—Evolution of the hind foot of the horse. Side views of six stages, eohippus, mesohippus, miohippus, merychippus, hipparion, equus. (Osborn.)

and increasing considerably the strength of the joint. By this means the foot is made more efficient for locomotion over a smooth surface, but less so for traveling over very rough ground, and it becomes of little use for striking or grasping or the varied purposes for which the feet of polydactyl animals are used.

The increased length in the lower leg and foot increases the length of the stride without decreasing its quickness. The heavy muscles of the leg are chiefly in the upper part, and to increase the length of the lower part changes the center of gravity of the limb very little. Consequently the leg swings to and from the socket nearly as fast as before, since in an ordinary step the action of the leg is like that of a pendulum, and the speed of the swing is regulated by the distance of the center of gravity from the point of attachment, as that of a pendulum is by the height of the bob. To increase the length of a lower leg and foot therefore gives the animal greater speed; but it puts an increased strain on the ankles and toe-joints, and these must be strengthened correspondingly by converting them from ball-and-socket joints to "ginglymoid" or pulley joints. Additional strength, likewise at the expense of flexibility, is obtained by the consolidation of the two bones of the forearm (ulna and radius) and of the leg (tibia and fibula) into one, the shaft of the smaller bone practically disappearing, while its ends become fused solidly to its larger neighbor.

The increase in length of limb renders it necessary for the grazing animal that the head and neck should increase in length in order to enable the mouth to reach the ground. An example of these changes is the modern horse, in which we find the neck and head much elongated when compared with the little Hyracotherium and this elongation has taken place *pari passu* with the elongation of the legs. The reduction and disappearance of the side toes and the concentration of the step on the single central toe serve likewise to increase the speed over smooth ground. The soft yielding surface of the polydactyl (several-toed) foot is able to accommodate itself to a rough irregular surface, but on smooth ground the yielding steps entail a certain loss of speed. A somewhat similar case is seen in the pneumatic tire of a bicycle; a "soft" tire accommodates itself to a rough road and makes easier riding, but a "hard" tire is faster, especially on a smooth road. Similarly, the hard, firm step from the single toe allows of more speed over a smooth surface, although it compels the animal to pick its way slowly and with care on rough, irregular ground.

The change in the character of the teeth from brachydont or short-

crowned to hypsodont or long-crowned, enables the animal to subsist on the hard, comparatively innutritious grasses of the dry plains, which require much more thorough mastication before they can be of any use as food than do the softer green foods of the swamps and forests.

All these changes in the evolution of the horse are adaptations to a life in a region of level, smooth and open grassy plains such as are now its natural habitat. At first the race was better fitted for a forest life, but it has become more and more completely adapted to live and compete with its enemies or rivals under the conditions which prevail in the high dry plains of the interior of the great continents. The great increase in size, which has occurred in almost all races of animals whose evolution we can trace, is dependent on abundance of food. A large animal, as may be shown on ordinary principles of mechanics, requires more food in proportion to its size than does a small one, in order to keep up a proper amount of activity. On the other hand, a large animal is better able than a small one to defend itself against its enemies and rivals. Consequently as long as food is abundant, the larger animals have the advantage over their smaller brethren, and by the laws of natural selection the race tends to become continually larger until a limit is reached, when sufficient food becomes difficult to obtain, the animal being compelled to devote nearly all its time to getting enough to eat.

Reconstructions.—When you visit a museum the entire skeleton of a fossil horse, dinosaur, elephant or man is exhibited. No one has found the entire skeleton of such animals except in rare instances. How have these parts been reconstructed and do they correctly represent the missing parts?

In all such specimens the fossil parts are shown in one color and the manufactured parts in another. (Fig. 197.) The expert employs certain methods in making these reconstructions.

In the first place he accepts as a *fact* that the skeleton of a vertebrate consists of a limited number of distinct bones and that these extinct vertebrates did not possess any new or different bones than those living today. The changes in proportion then are the main problems to be studied.

Erwin S. Christman, who died in 1921, was one of the most successful workers in this highly technical field of research. Prof. Gregory says that Christman studied with unending patience and enthusiasm the elaborate construction of the backbone of an extinct monster, making hundreds of drawings of the separate vertebræ,

correcting the distortion of the crushed bones, and supplying in dotted lines the probable appearance of missing parts as deduced from comparison with other specimens. The Camarasaurus bones (a dinosaur), furnish a good illustration of his method. The remains of several individuals were found in a quarry, scattered in almost hopeless confusion. As the individual vertebræ are too heavy to be handled easily, and literally too big to be studied closely in series, Christman's drawings afforded the means of making effective comparisons of the vertebræ with others of the same

FIG. 197.—Restored model of Piltdown skull by Dr. Smith Woodward. The fossil parts are black and the restored parts are white. Do you think that these white parts are correct? (Photograph furnished by American Museum of Natural History.)

animal and with homologous vertebræ of other individuals. After the probable associations of vertebræ with each other and with the appropriate girdle and limb bones, had been worked out, Christman made a new set of drawings on a smaller scale of every part of the completed animal. Each of these drawings he then carefully cut out with scissors and fastened to flexible copper wires. The model of the whole vertebral column was then laid out on a black background and adjusted to similar models of the ribs, girdles, limbs and skull. By means of this flexible model various

possible poses of the skeleton were represented and photographed. After a certain general pose of the skeleton was agreed upon, Christman constructed a plasticene mannikin of the skeleton, accurate in proportions and mounted on flexible lead wires. The next step was to determine the location of the principal muscle masses of the girdles, limbs, and body. This again was a by-product of previous studies of the musculature of reptiles and mammals and Christman showed his usual intelligence and skill in adapting this knowledge to the special problems in hand. Thus he produced one of the most successful of all restorations of dinosaurs yet made.

Homology.—In the preceding section on Reconstructions, the principles of homology and correlation were employed. What are these two important principles of interpretation and what facts adequately justify their use?

We must constantly keep in mind that all organisms consist of similar units, cells; and that these units are grouped into similar tissues. There are but a few different kinds of tissue in all animals and the same can be said for plants. These tissues unite in various ways to form the organs of the body. The digestive canal of a vertebrate is similar in its tissue components whether one analyzes a fish, a turtle, or man. There are but two main classes of muscle tissue in all animals, one of which becomes specialized into the muscle of the heart. Protecting, supporting, conducting, and storage tissues include the chief plant tissues. By various groupings of these a multiple flora has resulted.

More specifically the student of a given class of organisms is familiar with these basal facts as they apply to all organisms and he concentrates his attention upon their modifications as they apply to the special animals or plants that he is studying. He must scrutinize very closely the extent of the modifications in order to determine the exact relationships. In doing this he is guided by certain principles of interpretation which may be illustrated as follows. In Fig. 198 is shown a number of limb skeletons. The bones in the legs of these different animals vary greatly in length, thickness, and smoothness, but there are no new bones. The students of embryology have noted very carefully how these bones arose in each of these modern animals, and it was found that they had a similar origin. This means that the bones and the muscles which move them arose in the embryo in similar fashion. The same may be said for the anterior appendages of vertebrates; in fact, it would be correct to say that the entire skeletons of all vertebrates have had a similar origin. It seems a bit

strange to compare the short jaw of man with the long jaw of a horse or an alligator, but the fundamental plan and method of formation is the same in each case. The same may be said of the muscles, nervous system and all of the organs in the body of the vertebrate.

Homology Defined.—*No matter how different the general appearance of organs or structures, and no matter how different their general function, if they can be shown to have had a common origin, they are said to be homologous.* Homologous organs usually have the same

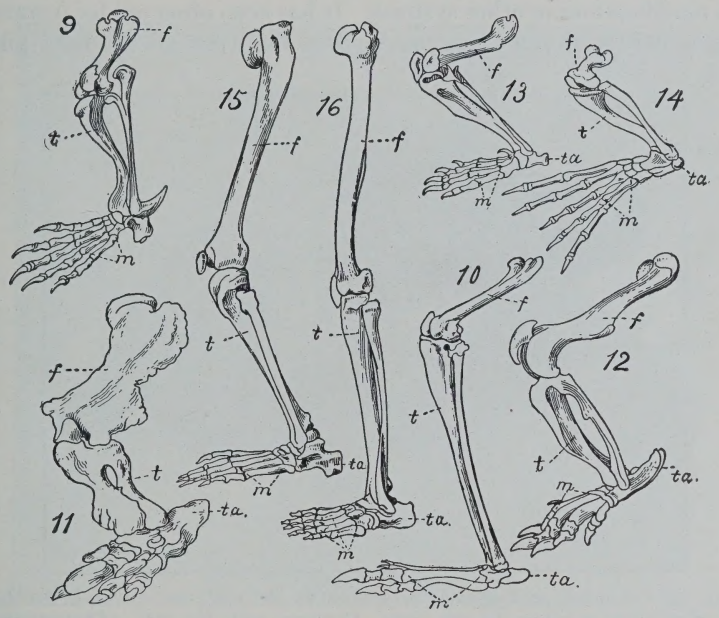

FIG. 198.—Limb skeletons of various animals showing homologous bones: *9*, ornithorhynchus; *10*, kangaroo; *11*, megatherium; *12*, armadillo; *13*, mole; *14*, sea-lion; *15*, gorilla; *16*, man. (From Jordan and Kellog.)

relative position on the animal. This means that organic beings are constructed of corresponding parts and that the main difference between them consists in variations in the original and fixed number of elements. An element may be large in one animal and small in another; simple or complex, as in the appendages of crayfish (Fig. 141).

The chief difference in the group of vertebrate animals consists in variations in the number of fixed elements that constitute the typical vertebrate. This study of homology serves to show the relationships in similar and also in some divergent adult morphological structures.

The homologies in the family of Ranidæ, for example, are very close, because all of the true frogs have sprung from the same stock, while the homologies between fishes and amphibians are more general. So far as it is known homologies never arise in organic nature except through genetic relationship.

Correlation.—Intimately associated with homology is a further extension of the same principle of interpretation. There are found to be certain constant relationships in animals of a given class. The structures of one organ system are found to be correlated with certain modifications in other systems. It has been observed for instance that animals with only two chambers in the heart always have gills,

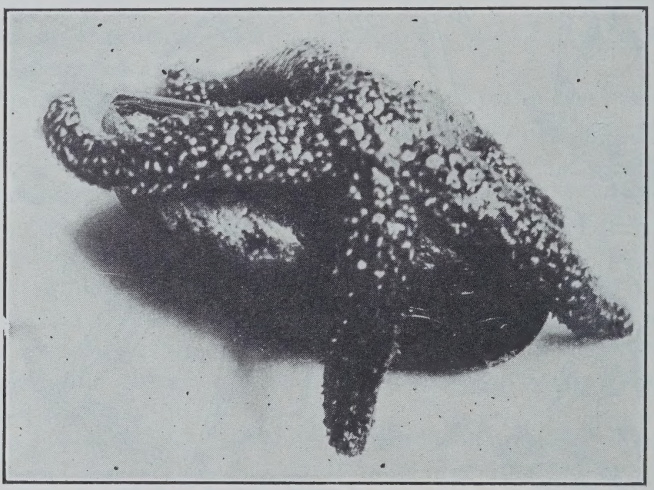

FIG. 199.—Star-fish photographed in position to pull apart the valves of the clam shell preparatory to eating the soft parts. Compare with Fig. 200. (Photographed by I. A. Field.)

live in the water, use fins in locomotion, and have the body covered with scales. It is also observed that animals which have four complete chambers in the heart never breathe by gills, never live in the water, have the body covered with feathers or hairs and are warm-blooded. These combinations are thus said to be correlated. If one finds a tooth of a fish, Fig. 190, in the rock, he can tell from the shape of the tooth the kind of food which the fish takes, and therefore reconstruct many of its habits as well as parts of the skull; or, if he discovers the vertebræ belonging to some unknown animal he can possibly reconstruct the entire vertebral column.

The same principle is applied in hunting for species of animals

that must have been the ancestors of fossil types already discovered. Men become so expert in the application of this principle that they are able to detect a new fossil at a glance.

The application of these principles, homology and correlation, have yielded splendid results in the attempts to write the history of extinct life and to point out its relation to present day life. We are now able to describe not only the general form of many extinct animals but to indicate their habits of living. Fossil star-fish have been discovered wrapped around fossil clams just as they can be seen today

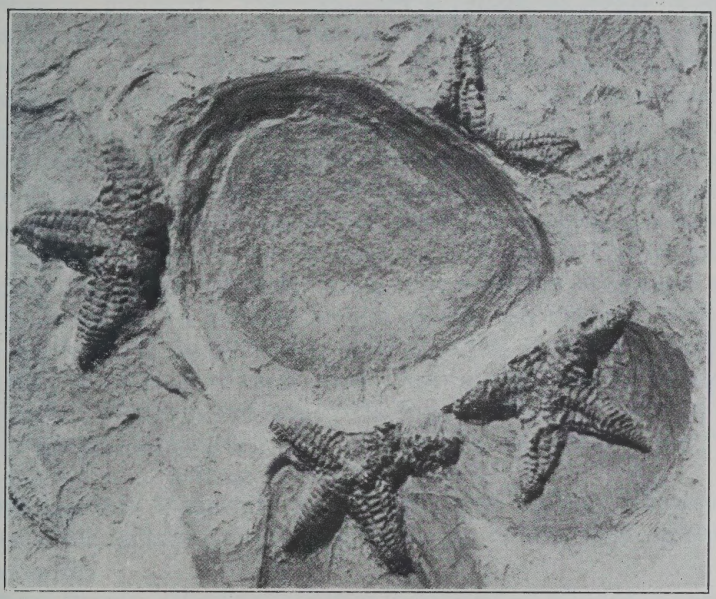

FIG. 200.—Fossil clams and star-fish preserved in such close association as to suggest that the star-fish were feeding on the clams. (From John M. Clark.)

(Figs. 199 and 200). So complete are the records of some species that the entire embryonic history is known, and in every instance these fossil animals have grown from like animals and have gradually become differentiated into adults. Through these studies we have learned much about the beginnings of some of the great classes of plants and animals, although much remains to be discovered. All fossils can be classified on the basis of their structural relationship just as modern plants and animals are classified. All the facts thus far accumulated indicate that there has been a definite continuity of life from the remote past to the present, and that the animals and

plants which lived in ancient times were governed by the same principles as those of today.

The student is expected to read some of the following references in order that he may more completely fill in the outline presented in this chapter.

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CHAPTER XXIV.

ADAPTATION.

The term, "adaptation" is one of the most frequently used words in a general discussion about the habits and adjustments of organisms to their environment. There are various definitions which indicate that this term may be used to explain the usual daily routine of life, or only the unexpected vicissitudes of life. Living organisms present a rather wide range of activity and reactions occur in the continuance of life without any special development of structures. Parker defines this term as follows. "An adaptation is not only a favorable response, it is a favorable response especially developed to meet a particular emergency." The fundamental life process of respiration occurs in the paramecium, in the fish, in the frog, and in man. In the paramecium no special structures assist this exchange of oxygen and carbon dioxide. In the fish the gills assume this function, while in the frog both the lungs and skin enter upon this important work, but in man the exchange of these gases is limited to the lungs. The gills of the fish, the lungs and skin of the frog, and the lungs of man are the structural adaptations especially developed to assist in carrying on this essential activity in these animals.

Food-getting.—Formulate your own outline of the manifold adaptations which animals have to assist them in securing their necessary food energy.

Sense Organs.—Possibly no better illustration of adaptation can be cited than the sense organs of animals, each of which is specialized to respond to conditions in the environment. The compound eyes of the crayfish and the eyes of the frog are stimulated by ether waves vibrating between 400,000[1] billion and 800,000 billion times per second. Such vibrations produce light and color and the only sense organ that can be stimulated by these waves is the eye. When the ether vibrates more than 800,000 billion times per second as it does, animals and man have no sense organs that enable them to become aware of the ultraviolet rays, x-rays or the emanations of radium, which we have come to know about through the use of special physical apparatus.

[1] See Herrick: Introduction to Neurology. Table of Physical Vibrations.

A study of the physical vibrations in nature reveals that we have sense organs for only a small number of them. We all know that the human ear responds to vibrations from 30 per second to 30,000 and that we have no sense organs that are responsive to vibrations below 30 per second and none above 30,000 until we come to 3000 billion vibrations when the skin gives us the sensation of heat. In the aquatic vertebrates are found some special sense organs that are believed to respond to vibrations below 30 per second. These are the lateral line organs (Fig. 201).

FIG. 201.—Salamander, showing the location of the lateral line sense organs. Each spot represents a pore opening into a canal in which are special sense cells (Fig. 48, *B*). The exact distribution of these sense organs varies with each species. This species is *Gyrinophylis porphyriticus*, one-half natural size.

A little reflection on your part will easily convince you that we live in a world in which our sense organs give us incomplete information concerning the activities in the physical universe; in short, we possess sense organs adapted to give us information on scarcely more than half of the physical vibrations constantly about us. The sense organs thus serve to reveal the extent to which protoplasm has become modified under adaptation and the limits of protoplasmic adaptability in that animals have never developed sense organs to respond to many of the physical vibrations.

Not only do animals vary greatly in their receptors but remarkable changes have taken place in the internal nervous system. In the earthworm and the crayfish, ganglia are present in practically all of the segments of the body. The same is true of the larval stages of insects but when the adult nervous system of certain insects is studied, the ganglia are concentrated in the head and thorax, Fig. 202, indicating that there is a profound re-arrangement during pupation.

The changes in the central nervous system of vertebrates is too technical to present in detail but it may be pointed out that there have been additions, condensations and eliminations of parts as is shown in a careful study of the several classes of vertebrates. As animals have become adapted to their several environments numerous structural changes have taken place in their nervous mechanism.

Reproduction.—In classifying reproduction under adaptation it is not intended to suggest that this fundamental characteristic of living protoplasm is an adaptation but rather to direct attention to the significant results that follow from normal reproductive activity. Attention has already been directed to Professor Woodruff's experiments on paramecium (page 124). The rate of reproduction observed in these studies was three divisions in forty-eight hours, and

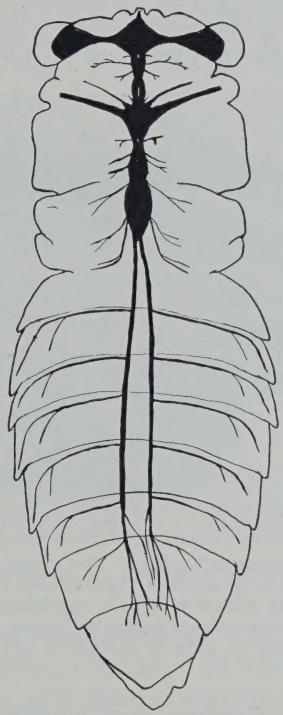

FIG. 202.—The central nervous system of Cicada, adult, showing the concentration of the ganglia in the head and thorax.

at the end of the experiment, the animals appeared as healthy as in the beginning. During this time, if all generations could have been observed and all had been as active as the strain preserved, there would have been a mass of paramecium protoplasm more than 10,000 times the mass of the earth!

"An oyster may have 60,000,000 eggs, and the average American yield is 16,000,000. If all the progeny of one oyster survived and

multiplied and so on until there were great-great-grandchildren these would number 66,000,000,000,000,000,000,000,000,000,000,000, and the heap of shells would be eight times the size of the earth!" Lull.

The insects show a similar form of reproductivity. A single flesh-eating fly (*Musca carnaria*) produces 20,000 larvæ, and these grow so quickly that they reach their full size in five days. Each of these larvæ remains in the pupa stage about five or six days, so that each parent fly may be increased two thousandfold in a fortnight. The great Swedish naturalist Linnaeus asserted that a dead horse could be devoured by three flies as quickly as by a lion.

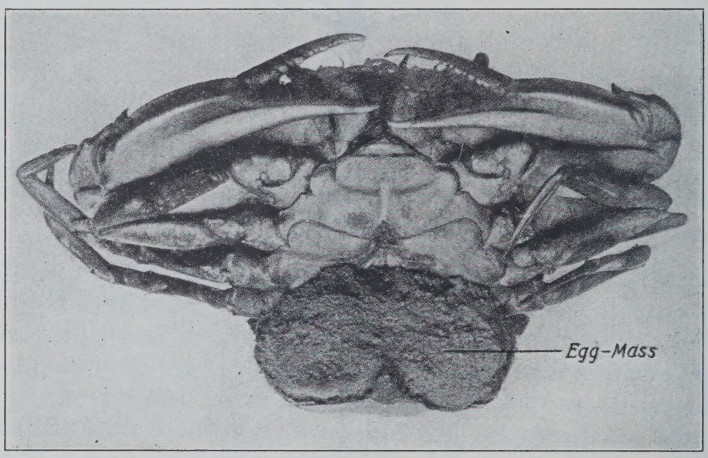

FIG. 203.—Blue crab, *Callinectes sapidus*. The young hatch from eggs borne for about fifteen days upon the swimmerets of the abdomen of the female in a mass called a sponge. There are about 1,757,000 eggs in one sponge. A female crab may lay two and probably more batches of eggs during the course of her life, the spermatozoa from one copulation sufficing to fertilize successive lots of eggs. (Photograph and legend from Churchill.)

Even some of the vertebrates show reproductive possibilities that would soon pack the ocean full of fish as the following taken from Lull shows: Among the lower vertebrates where no paternal care is given to the young the potential productivity is necessarily enormous. In four herring the number of eggs varied from 20,000 to 47,000; in a cod there were 6,000,000; a turbot, 9,000,000; and a ling, 28,000,000, and yet despite the enormous number of offspring which might possibly be produced from a single pair in one generation, the ultimate number of herring or cod or ling remains on the average about the same. The chance of survival, therefore, of a ling's egg is one in fourteen million.

If half of the 4000 eggs laid by a female salmon developed into females and reached maturity in four years, and this rate should continue from generation to generation, in thirty-two years there would be 256,000,000,000,000,000,000,000,000 salmon weighing 468 times as much as the earth.

Even the slow breeding of our common robin which raises annually one or two broods with an average of four young in a brood would produce in a short time so many robins that they would have to starve because there would not be enough robin food for them in the entire world. The following table from Metcalf shows how many robins there would be at the end of ten years:

	Adult.	Young.
One pair of adult robins	2	4
Second year	6	12
Third year	18	35
Fourth year	54	108
Fifth year	162	324
Sixth year	486	972
Seventh year	1,478	2,916
Eighth year	4,374	8,748
Ninth year	13,122	26,244
Tenth year	39,366	78,732
End of tenth year	118,095	

When one considers the energy required to produce such vast numbers of eggs and sperms some insight into the real meaning of this fundamental characteristic of protoplasm is gained. The production of so many living things causes keen competition for a place to live, for food and for an opportunity in turn to produce young, the significance of which is presented in the next general section of the text.

Regeneration and Grafting.—In the study of hydra attention was directed to the fact that these animals could regrow lost parts and that they could be grafted (Figs. 121, 122). At first scientists were inclined to regard this property as a phase of reproduction but it differs from reproduction in that it does not take place as a method of producing more individuals but in the repair of injuries. Grafting is not known to occur in nature.

Among all of the lower animals and plants a large amount of regeneration may take place, even to the regrowing of the legs on the crayfish or the tail and legs of an Amphibian. But as we pass to the higher animals this general property of regrowing lost parts is restricted to specific organs, such as scales, feathers, hair, the outer skin, the healing of a broken bone or the regrowth of antlers (Fig. 204). With the higher specialization of structures there has come a loss of the property of regeneration.

Biologists regard the study of regeneration and the experiments in grafting as very important in revealing a particular phase of protoplasmic adaptation that was overlooked for a long time. The special studies in this field of biology suggested and laid the foundation for certain phases of modern surgery in man.

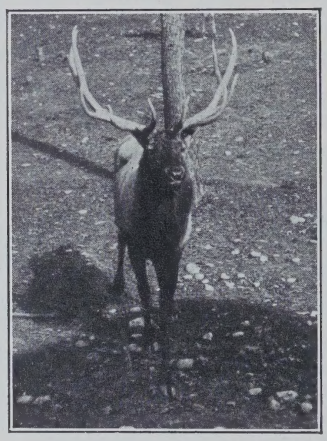

FIG. 204.—American elk. The antlers are borne only by the male and are shed annually in March. These interesting structural adaptations are to be regarded as secondary sexual characters.

Adaptations in the Pelvis.—The changes that have taken place in this bony girdle are closely associated with the habits of the various vertebrates. In salamanders, the pelvis is just beginning to form so that cartilage constitutes its main parts. The frog shows a well formed, bony pelvis with the ilium greatly elongated. Snakes and whales do not exhibit a pelvis except as vestiges, indicating that these animals have been derived from animals that possessed a pelvis. Climbing mammals like the sloth have the pelvis widened to give support to the organs in the abdominal cavity; while the bipedal mammals have this girdle modified both to support the visceral organs and to carry the entire body on the two legs.

The pelvis of all of the higher animals is built on the same plan and the student of adaptations can find many modifications that have taken place. Pocket-gophers are burrowing animals that have the pelvic girdle greatly reduced, apparently as an adaptation for turning in the narrow confines of the burrow. This reduction has gone so far that the parent cannot give birth to young until the union of the pelvic bones is dissolved. (Fig. 205).

A large number of pocket-gophers (Gromys bussarius) have been studied and it is found that the development of the pubic bones is the same in both male and female up to the approach of sexual maturity, being completely ossified in both. As the breeding season approaches, when the animal is a year old, the pubic bones of the pelvis in the female begin to be absorbed until they are freed from each other. The male pelvis remains united throughout life. These observations afford an illustration of important changes taking place in the skeleton of a mammal and furnish a practical example of how other alterations may have occurred.

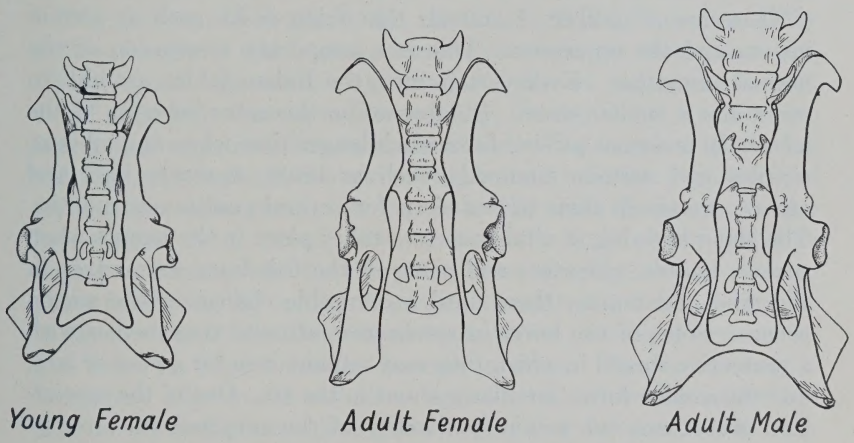

FIG. 205.—Pelvic girdle of the pocket-gopher. (Redrawn from Hisaw.)

Habit Adaptations.—The early studies in adaptation dealt especially with the modifications in the various parts of animals. These are more obvious than a physiological property. We shall simply enumerate them because their presentation would require many pages, but especially because you should become familiar with the general literature on this subject. Lull devotes one hundred pages to a discussion of these adaptations and makes the following classification: Cursorial or speed adaptations dealing with the modifications in form which help vertebrates to escape their enemies on land, in water or in the air; fossorial or adaptations to a subterranean life, such as those who dig or burrow for food; aquatic adaptations dealing with the general form of the body and the organs of locomotion in such form as fishes and whales; scansorial adaptations where animals become partly or wholly arboreal; volant or flying adaptations in fishes, reptiles, birds and mammals; adaptations to cave and deep-sea life.

Duration of Life.—The answer to the query, How long does a given species live is associated with several factors. There is no question but that death has come to be a permanent part of every organism that reproduces sexually, and, even some of the recent writers claim the same for the unicellular forms of life. The various adjustments which living things have made that enable them to prolong their lives reveal a range of adaptation much greater than commonly supposed, as the following brief summary of their adaptation to heat, cold and desiccation indicate, where suspended animation, first a necessity, has now become a normal part of their seasonal habits.

There are a number of animals that feign death such as certain insects and the oppossum. This is a temporary suspension of the normal animation. Even certain men, the Indian fakirs, are able to enter into a similar state. In hibernation this same lowering of the metabolic processes persists for a much longer time when amphibians, reptiles and certain mammals, such as bears, squirrels, bats and others, remain in their winter sleep for several continuous months. The same lowering of vital processes takes place in the tropics when snakes, insects, alligators and some of the fish bury themselves in the mud and remain there until a favorable change in the season occurs. Some of the lower invertebrates surround their bodies with a protective sheath in which they may remain even for a year or two, and the smaller forms are blown about in the air. One of the specialized protozoans can retain its vitality in the encysted state for at least fifty years. Freezing is quite the opposite to tropical conditions and in the arctic waters we find animals able to exist although they may be completely surrounded by ice. Fish and frogs can thus be frozen, and, if thawed slowly, will revive. One arctic species of fish has been kept in ice for four months and then revived. It would seem as if all metabolic processes must be completely suspended under such a long period of freezing.

Desiccation is the state in which animals are able to lose a certain amount of the normal water of the tissues and still continue to live. All protoplasm contains water and the amount varies from 50 per cent to nearly 100 per cent of the body weight. One hundred and fifty years of experimentation on the simpler animals, especially the rotifers, has revealed that they become immobile when gradually dried and are apparently dead. In this state they have been kept for six years and then revived. Hall has recently shown that the earthworm, Allobophora, can be exsiccated until 83 per cent of the water contained in the body is given up without loss of vitality, while the

leech, Placobdella, was dried until 92 per cent of the water was given off without causing death. Salamanders and frogs gave up 47 per cent and 50 per cent of the water. In the reptile group, turtles and lizards were able to survive after losing from 33 per cent to 46 per cent of the water from their tissues. Even such mammals as the mouse gave up 34 per cent of the water and revived. Animals are able to control to some extent the artificial exsiccation, for water is not given off as fast from their bodies as from a surface of free water. In salamanders the rate of evaporation was only one thirtieth times as fast as from free water.

The question of longevity has also been studied from an entirely different angle in which unexpected adaptations are met with. Fertilization and the artificial growing of cells are important factors. In all organisms that reproduce sexually, the egg which is to develop into a new organism dies unless fertilized. The length of time that this important cell will live and maintain itself in a state for successful fertilization varies greatly. In the sea-urchin which discharges its eggs into the sea about twenty-three hours is the limit after which they begins to weaken, and by thirty-two hours the eggs do not develop when fertilized. By adding a minute amount of potassium cyanide to the sea-water, the life of these eggs can be prolonged to seventy-five hours or three times the normal duration. This is, however, a temporary adjustment and these eggs like all others die unless fertilized. None-the-less it illustrates in a striking fashion the influence of a certain chemical in increasing the normal life of these ova. In a number of instances it has been possible to start the egg segmenting by either mechanical or chemical means which also enables it to escape death. When the ovum is thus started on its career, the method is called artificial fertilization and it has been successfully applied to a number of invertebrates and even to the frog.

Some ten years ago a method was devised by means of which living cells could be studied apart from the influence of their normal position in the body. These brilliant experiments have been made on the somatic cells and it has been found that such cells may actually live longer in this wholly artificial condition than when in the body of the chick, for example. The second important conclusion from this line of work is that the number of generations of cells that may arise is very much greater, for during the twelve years that connective tissue cells have been cultivated at the Rockefeller Institute, a single strain of cells has multiplied regularly during the entire time. From these studies it has been concluded that the differentiation of

cells into special tissues in animals has served to shorten their life and thus differentiation is one of the important factors in longevity.

From the simple hydroids and sponges comes additional evidence that the cells in these simple animals retain to a remarkable degree, the power to regrow the entire animal. For these same organisms can be cut into pieces so small that they will pass through bolting cloth and the isolated fragments will grow into small masses which gradually differentiate into a normal adult. (Fig. 123.)

These experiments on various phases of the problem of longevity raises the questions what is the limit of life and which animals live the longest. We naturally associate size with age thinking that the larger the animal the longer it took it to grow. The once famous elephant Jumbo reached his full height and weight in twenty-one years, growing in this time from 3 feet high and weighing a few hundred pounds to an adult 11 feet in height and weighing $6\frac{1}{2}$ tons. Lucas writing of the age of animals states that the great size of the tortoise which sometimes reached a weight 450 pounds or more was supposed to indicate a proportionately great age, but in seven years one increased from 29 pounds to 295 and in less than ten years weighed 350 pounds. If reptiles grow as fast as this nowadays, they probably did in the past and the huge fossil Brontosaurus and his kindred may not have taken more than a century or two to reach their 70 or 80 feet in length.

Among our modern vertebrates the pike and carp are reputed to live as long as three hundred and seventy-five years but this cannot be verified. Some of the tortoises live for two hundred years. Among the birds parrots have been reported on good authority to have attained to eighty years, while mammals do not often exceed one hundred years. This range in longevity clearly bears no relation to the size of the animal. Among the insects, the seventeen-year locust has the longest life span. The honey bee colony consists of a queen which lives from three to four years; drones that live but a few months; and workers whose longevity varies with the season. During the active period of summer, six weeks would represent the usual maximum time, while those workers that are hatched in the fall live until the spring brood of workers is ready to care for the colony. Among some of the other insects twenty-four hours cover the entire adult existence.

In amœba and paramecium as well as other unicellular organisms the entire body is continued in the two new individuals that result from fission. There is nothing left to die, hence death is not one of

their characteristics. But as soon as we consider the animals with tissue differentiation which is but another name for the development of soma as distinct from germ cells, then death appears. With the arrival of death, there are certain cells that live. It is the soma only that dies. Jennings expresses this idea of the continuity of life as follows: "The continuity of life in the infusoria is in principle much like that in ourselves, though with differences in details. As individuals, the infusoria do not die, save by accident. Those that we now see under our microscopes have been living ever since the beginning of life; they come from division of previously existing individuals. But in just the same sense, it is true for ourselves that every one that is alive now has been alive since the beginning of life. This truth applies at least to our bodies that are alive now; every cell of our bodies can be traced in an unbroken chain as far back into time as life goes. The difference is that in man and other higher organisms there have been left all along the way great masses of cells that did not continue to live. These masses that were worn out and died are the bodies of persons of earlier generations; but our own bodies are not descended by cell division from these; they are the continuation of cells that have kept on living and multiplying from the earliest times, just as have the existing infusoria."

As all of the complex animals grow older, there is a lessening of the rate of metabolism and a tendency to accumulate waste products in the cells such as vacuoles and various metaplasmic bodies. Eventually some set of cells fails to do its particular work and the metabolic balance is upset. Loeb writes on this phase of the problem as follows: "All this points to the idea that death is not inherent in the individual cell, but is only the fate of more complicated organisms in which different types of cells or tissues are dependent upon each other. In this case it seems to happen that one or certain types of cells produce a substance or substances which gradually become harmful to a vital organ like the respiratory center of the medulla, or that certain tissues consume or destroy substances that are needed for the life of some vital organ. The mischief of death in complex organisms may then be traced to the activity of a black sheep in the society of tissues and organs which constitute a complicated multicellular organism." We thus come to think of death as one of the most important of all of the adaptations.

Plasticity of Protoplasm.—One cannot but be impressed with the wide range of change existing in animal structures from the preceding outline of adaptations. Even the bony skeleton shows that important

elements have been either greatly reduced, as in the legs of seals or entirely omitted, as in the hind legs of whales. Usually these changes consist in strengthening certain parts and reducing others, such as the bones in the legs of a horse. In a general way we may designate this range of change in living things as plasticity. Sometimes this term is restricted to the changes that can be induced during the lifetime of an individual, changes which are frequently designated as the modifications or modifiability of parts in an organism. In this use of the term the reference is to the influence of environment upon an individual, such as when an Englishman in foreign service becomes, in the course of half a lifetime of work under a tropical sun, so thoroughly tanned that the browning never disappears even after he has returned to a temperate climate. Whether we use the term plasticity in the broader sense or in a restricted way it is a valuable term to help us to visualize the general concept of adaptation as outlined in this chapter and furnishes a convenient term to describe one of the fundamental characteristics of protoplasm. Adaptation is possible, then, because of the general and universal plasticity of protoplasm.

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LULL: Organic Evolution, Chapters XVIII to XXIV.
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CHAPTER XXV.

GEOGRAPHICAL DISTRIBUTION AND THE MEANING OF COLOR.

Environmental Changes.—As we try to reconstruct the living conditions under which the present habits of animals became established, it is important to realize that the several factors in the environment, such as climate, land, and water have undergone a progressive series of changes.

The present climate of the world has had its own history. Winter, spring, summer, and fall are a relatively modern development. The life of Greenland and Alaska during the Tertiary Period indicates that a tropical climate prevailed for tree-fern and corals are found in the rocks. The tree-fern requires a mild, moist, climate and corals are found only in warm waters. These and other fossils show clearly the degree of change that has taken place in this region.

With the advent of the glacial periods, extreme cold prevailed, and even plant life was destroyed. Thus a different condition entered into the climate and those animals and plants that could not migrate were blotted out. Organisms too highly specialized to change their habitat became extinct. It was not until after the last glacial period that the modern succession of seasons was established.

The varied conditions under which life existed during these and other changes are difficult to appreciate in our rhythmic succession of the seasons. Great land areas were frequently inundated by warm ocean waters. The North American continent was submerged no less than seventeen times over an area of from 154,000 to 400,000 square miles. When such floods came, profound changes were produced in the life of these regions and with the vanishing of the floods a cooler and drier climate followed which again demanded a radical change in the habits of the organisms of the areas.

If we simply enumerate a few of the changes that have occurred in climate, land, and water it will be evident at once, that life during these changes was subjected to more extreme conditions than occur now. During the coal-forming period a warm, humid, atmosphere obtained. The glacial periods produced extremes of cold followed

by a very much warmer temperature. The elevation of great masses of land into mountain ranges established barriers and limited migration. Volcanic eruptions destroyed all life that came in contact with the molten lava. The waters of the world became restricted within narrower limits than formerly, as it is not generally held that the amount of water has greatly increased in geological history. This resulted in deep oceans taking the place of the shallower seas of ancient times. To all of these changes and many others the fauna and flora became adjusted. So if one would understand present habits and adaptations, these environmental changes must be considered as they played their part in shaping the life of our day.

The range in temperature during all of the vast time included in biological history was limited to the difference between freezing and about 150° F. Life could not exist where the temperature was always below freezing nor is there any evidence that the range was greater than 150° F. The forms of life that are found in the rocks of this earliest period are in many instances similar to those that are living today. Similar chemical elements were in the atmosphere for there has been no marked change in these requirements for life. The amount of heat given off by the sun probably was not much different from that in our age. If it was greatly different in the past then the climate would have been so unlike that of today that the earlier forms of life would have been compelled to live under conditions so wholly different from ours that it is hardly conceivable that they could have been the ancestors of our modern life. Life has existed during all of its history of more than one hundred million years within these relatively narrow limits.

This brief sketch of some of the more conspicuous changes in the past environment of animals and plants furnishes a background for the study of geographical distribution which includes the present distribution of organisms and offers explanations for their adaptations to the varied habitats in which they are found.

The analysis of the causes which determine the present distribution of organisms on land and in the sea is beset with many difficulties even to those who have given years of study to the problem. For this reason beginning students should be cautious in their generalizations. At all times one must keep in mind the biogenetic law and its implications that not only do all members of a genus but also all members of the great classes or phyla have a common ancestry.

The well-known biological fact of geographical distribution is illustrated by all groups of animals and plants when all of the members

of a genus are taken into consideration. In our general studies we are restricted too often to but one species of frog, sparrow, crayfish or trillium with the result that the important biological fact of distribution is wholly unappreciated. The following facts and Figs. 4, 5, 206, 207, taken from some of our most familiar animals, clearly indicate the meaning of geographical distribution.

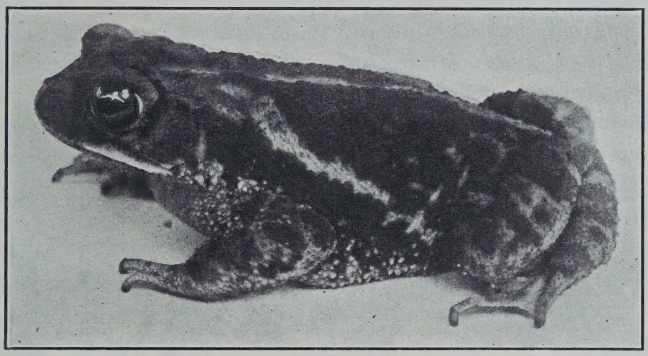

FIG. 206.—*Bufo valliceps*, a Mexican toad. (Photographed by M. C. Dickerson.)

When one examines the genus Ranidæ he finds that the sixteen species in North America have the following living conditions: Rana pipiens is the most common frog in North America east of the Sierra Nevada Mountains and is the only frog found between the

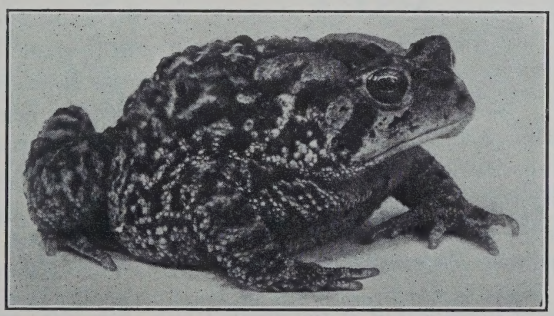

FIG. 207.—*Bufo cognatus cognatus*. Reported from Nebraska, Kansas, Arkansas and Arizona. It is probably found in other States of the Western plains as well as in other of the Rocky Mountain regions. (Photographed by M. C. Dickerson.)

eastern part of the Great Plains and the Sierra Nevada Mountains. Rana sylvatica is a swamp-inhabiting frog in the northeastern part of the United States. Rana sphenocephala, R. areolata, R. œsopus and R. grylio are limited to the States of Georgia, Florida, Mississippi

and Texas. Rana palustris, R. clamitans and R. catesbiana are each common throughout eastern North America, including Canada. Rana onca, R. drytonii, R. aurora and R. boylii are found only on the pacific slope of the United States and in Utah, Nevada and Oregon. Rana virgatipes has been reported only from New Jersey; while R. cantabrigensis and R. septentrionales are wholly northern species found chiefly in Minnesota, Wisconsin, the Adirondacks and Canada.

These familiar animals must have migrated from some one place according to the law of biogenesis before they became fixed in their present habitats. It is also to be noted that such species as R. pipiens, R. palustris, etc., are able to live under a wider range of environmental conditions than either the southern or western members of this genus.

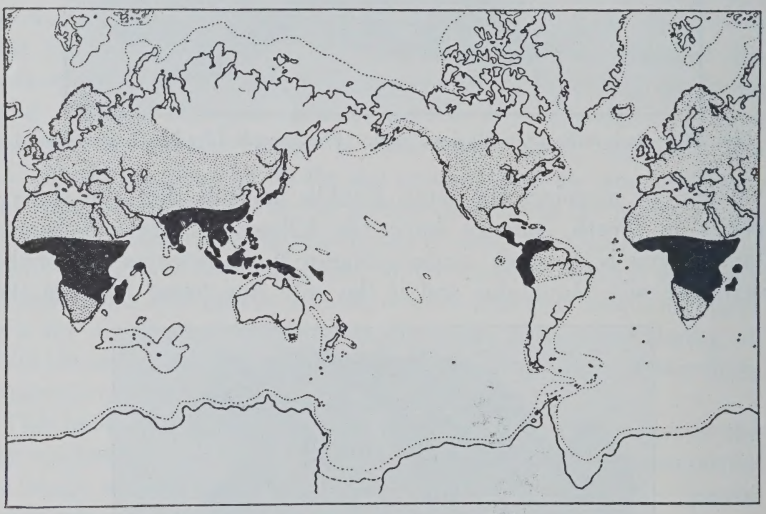

FIG. 208.—Distribution of Ranidæ. The presence of genera other than Rana is indicted in black. Rana is found over both the stippled and the black areas except that it is absent from Madagascar and Seychelles Islands. (Metcalf.)

The present distribution of the genus Rana (Fig. 208) and a study of its Opalinid (protozoan) parasites indicates a probably northern origin of this genus. Except for a single species in northern South America, several species in Papua, one Papuan species in the northernmost tip of Australia, and three species in the Solomon Islands, they

[1] The Origin and Distribution of the Anura. M. M. Metcalf, American Naturalist, 1923, **57**, 398.

have not penetrated into the southern hemisphere except in Malaysia and in Africa. Their entrance into the Malaysian Islands and Papuasia was probably in the late tertiary, and their entrance into tropical Africa may well have been by way of the Nile valley, this also in later tertiary times. Fossil Ranidæ are known from European rocks of the lower Miocene and perhaps of the upper Oligocene. Other genera of the same subfamily, Ranidæ, have an equatorial distribution and we seem to find nothing in themselves, their fossil remains, or their Opalinids, to determine definitely whether their original habitat was in "equatorian" lands or was northern.

Frogs and toads have been in existence for a long time, possibly ever since the Devonian geological period. Since that time there have been many changes in the earth surface of the North American continent and the climate has shifted from a tropical, moist stage to our present North temperate and Arctic zones, with its annually recurrent winters that have forced the Amphibians to take up the hibernating habit. Thus while temperature may be the main barrier that keeps modern frogs and toads from having a universal distribution in the temperate region it is a condition that has not always existed.

Amphibians are not found on the high mountains or in northern Canada because it is too cold for them, nor are they found in the sea or on oceanic islands because they cannot live in salt water. Thus the salinity of the ocean becomes an effective barrier to the migration of frogs from one continent to another or from the mainland to nearby islands. Temperature, mountain ranges and bodies of water constitute the great outstanding barriers which prevent indiscriminate migrations of animals at present.

Some writers have mapped North America into zoögeographic realms or divisions, using the isothermal lines to indicate the boundaries such as the Arctic, which includes all land north of the isotherm 32°. In a very general way this is helpful, but fails when applied in detail. There is such a vast difference between the swamp conditions on the one hand and the arid plains on the other, both of which may be in the same temperature belt, that no comparison of the environmental factors is possible, nor can the organisms found in the swamp habitat be transferred to the arid plain conditions (Fig. 209). There is something more fundamental than temperature that determines the present distribution of animals and plants in North America.

The migrations which once took place in the genus Ranidae and Bufonidae have resulted in the present permanent distribution of

these species in North America. It is the conviction of students of organic distribution that the impelling cause of such migrations was a changing climate, an increase in competition for food, a place to live and protection from enemies.

Several prehistoric migrations have been unravelled through a study of the fossils found in regions now separated by barriers such as the general distribution of fossil elephants in Asia and North America from their original home in Africa; or the migrations of camels from North America into Asia and of the llamas (relatives of camels) into South America.

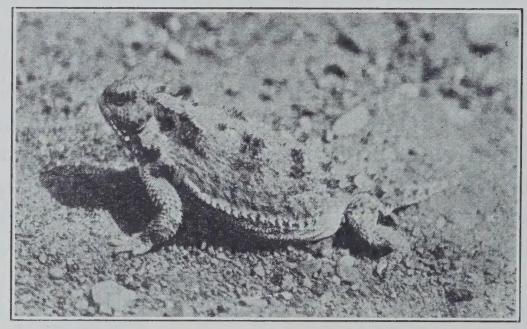

FIG. 209.—The common "horned toad" of the arid west. (Photographed by A. G. Rutheven.)

Such migrations are better understood by a study of the seasonal migrations of the modern caribou, seals, salmon, "Rocky Mountain Locust" and birds. The instinct which impels salmon to leave the salt water and ascend the Columbia and Yukon for thousands of miles to lay their eggs and then die; or the unerring accuracy of the seals as they make their journey of fifteen hundred miles so as to arrive at the Pribilof Islands at about the same date each year, helps one to understand how some of the prehistoric migrations may have taken place (Fig. 217).

The preceding paragraphs considered chiefly terrestrial distribution. Another phase of this same subject is the distribution of life in the great bodies of water, both fresh and salt water. Here it is customary to divide all large bodies of water into three regions or realms: (1) Littoral, (2) pelagic, (3) abyssal.

The littoral or shore division consists of the organisms that prefer shallow water, tide pools and coral reefs. This shore fauna and flora is more abundant in species than any other and often every available

place is occupied by some form of life. In no place is the keen struggle for a place to live better illustrated (Fig. 210).

The pelagic realm embraces all of the surface waters and is limited to the depth to which sunlight penetrates which is a little over five hundred feet. Storms and waves disturb the surface waters of this division while its lower strata remain relatively calm. Pelagic fish move in schools and are usually powerful swimmers. Multitudes of invertebrates occupy this realm, floating and drifted about by the tides and winds.

FIG. 210.—Mussel community, showing abundance of life in shallow water. "Actual measurements of the most thrifty beds gave a yield of one and one-half bushels per square yard or seven thousand bushels per acre." (Photograph taken in Pond, Martha's Vineyard, not far from Gay Head, by I. A. Field.)

The abyssal realm is defined as the area below six hundred feet. This realm is characterized by an entire absence of sunlight; by no movement of the water aside from slow ocean currents; by an average temperature in the Atlantic of between 37° and 35.6° C. and by an enormous pressure from surrounding water. At sea level the pressure is fifteen pounds to the square inch, while at six thousand feet it is about one ton to the square inch.

In the abyssal depths are found many fish with odd shaped bodies moving about in complete darkness, except for a dim phosphorescence produced by themselves (Fig. 211).

FIG. 211.—"A small, silvery, eel-like fish which has been found in all the oceans at depths ranging from a little less than a mile to two and a half miles. It has a row of luminous pores running the length of the body, and in the blackness of the profound depths it must appear like a miniature long dark boat with gleaming port-holes. Its greenish, glittering eyes are perched on the ends of slender horn-like tentacles—a feature which has suggested its scientific name, *Stylophthalemus paradoxus*." Redrawn from Hussakol Amer. Mus. Jour., 1915, xv, 252.

The animals that have become adapted to one of these distinctive habitats seem to be restricted to it, although there are no actual barriers. There is, however, an intermediate fauna which passes from the littoral over into the pelagic on the one hand or over into the abyssal on the other. Jordan found that the pelagic conditions act as a barrier to shore forms, since certain species of fish along the coast of California are similar to the shore fish about the islands of Hawaii, the open sea being the only barrier keeping them apart.

This outline on geographical distribution aims to help you in stating the general problem of the present distribution of organisms in space. In order to understand their distribution in time, some knowledge of geological history is indispensable.

The distribution of animals and plants in space and time is a study of the end-results of their relations to an environment that has undergone many changes. At present there is no way of computing how many species have become extinct during the many adjustments that each genus has been compelled to make. There would be no problem to solve in this study of the results of migrations were it not for the accepted fact of biogenesis and the rules of interpretation formulated by the scientific method.

MEANING OF COLOR.

No training in biology is necessary to indicate to one the range of color in Nature. Even in the north temperate region there is much variety, but this is insignificant in comparison with what is found in the tropics.

Organic color is produced in just the same way that color in the inorganic world is formed. *Color is some interference with the rays of light either by pigment or by the structure of the surface on which the light falls.* The former are known as the chemical or pigment colors and the latter as physical colors. It frequently happens that a given color is due to a combination of these two causes, which is then known as a chemico-physical color.

Chemical colors are found in all parts of the animal body, such as the hemoglobin of the blood, a red color due to an iron compound or a brown pigment in the kidney. The skin of the frog has brown blotches, due to pigment in the dermis, while fat pigments, called lipochromes, are abundant in the feathers, bill and feet of birds. Some of the most beautiful pigment colors occur on the inside of certain mollusk shells, where they are never seen until the soft parts of the animal are removed from the shell, and in the Cœlenterata, which are animals that do not possess eyes.

Physical colors give us white when there is a total reflection, or metallic color, due to refraction or iridescent color caused by diffraction. The feathers on the neck of a humming bird or a pigeon furnish a good illustration of physical colors.

Under some conditions color fails to develop in an individual, and there is a total lack of color in the hair, as, for example, a white woodchuck, or in the feathers, as in a white robin or a white sparrow. This lack of color is known as *albinism* and is a condition that occasionally occurs in man, resulting in a pink iris. Such people cannot endure strong sunlight. The opposite condition to albinism is an excessive production of pigment, to which the term *melanism* is given.

With the advent of Darwin's theory of the origin of species by Natural Selection, color came to have a definite meaning. Students of the problem of color then began classifying color according to its possible uses in the life of animals, which has given us the following: Warning colors; terrifying manners; mimicry or protective coloration. Each of these implies that color serves some useful purpose to its possessor. Even these general classes of color are divided until one has sympathetic, alluring, warning, mimetic, signal and recognition, confusing and sexual colors.

Under sympathetic color is grouped the blending of the color of an animal with its surroundings as it hunts or is hunted. The owl and grass snake illustrate this idea as do those animals that undergo a seasonal change of color, such as the white hair of the weasel in

winter and its reddish brown in summer. Many of the arctic animals have a winter dress which completely harmonizes with the snow and ice (Fig. 212). Several species of spiders have their bodies colored like the flower upon which they rest as they lie in wait for the unwary insect seeking pollen. Some fishes have a modified portion of the dorsal fin highly colored which they dangle in front of their own mouths. This is interpreted as a lure that assists them in capturing their food.

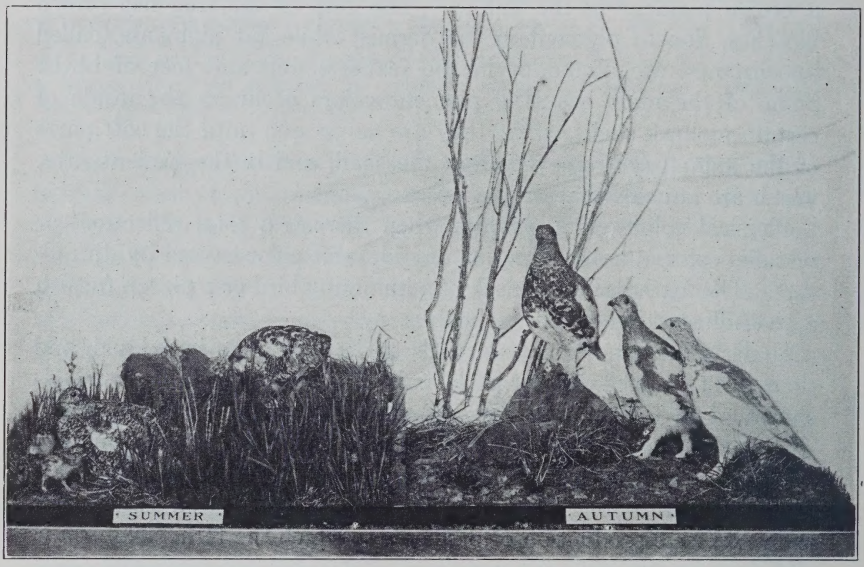

FIG. 212.—Seasonal variation in color of ptarmigan. (Photograph by American Museum of Natural History, New York.)

Conspicuous red and yellow colored animals are usually unpalatable or deadly poisonous, and so these two colors are considered as warning colors. The hornets, the Gila monsters and many caterpillars and butterflies are the usual examples given under this subdivision.

Any one who has seen a herd of Virginia deer in nature or even in a zoölogical park is at once struck by their habit of showing their "flag" when frightened or injured. The flag is the conspicuous white patch of hair on the under side of the tail and adjacent parts. The tail is raised when the deer is frightened, thus exposing a large white area which is hardly noticeable when the tail is in its natural position.

When this large white patch is shown it acts as a signal to the rest of the herd and all flee (Figs. 213, 214).

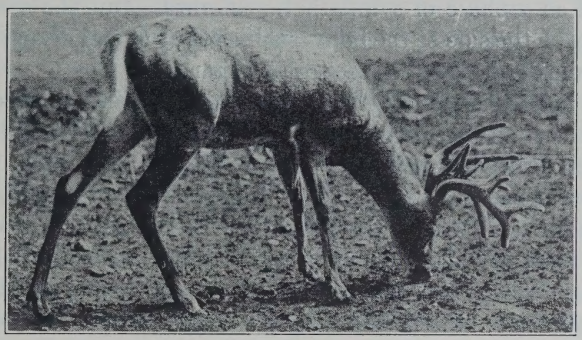

FIG. 213

FIG. 214

FIGS. 213 and 214.—Deer with the "flag" down and with the "flag" up. Note the alert attitude of the entire body when the "flag" is up. Courtesy of the New York Zoölogical Society. (Photographed by E. R. Sanborn.)

The colors on fish are often classed as recognition marks. Their dark colored backs conceal them when viewed from above and their light colored bellies prevent their being seen from below. This is regarded as a phase of sympathetic coloring. But the special color markings on the side of the body, such as the red and orange spot on a brook trout, are classed as recognition marks.

When a grasshopper alights we fail to see it unless the eye followed closely the jump or end of the flight. Many moths and butterflies with their brilliant colors are easily seen as long as they remain in flight, but when they alight the disappearance of the bright colors and the blending of the animal with the background confuses us. To this form of coloration we give the name protective (Fig. 214).

Among most of the vertebrates the male is more highly colored than the female, especially during the mating season. Birds furnish the classic examples of such sexual differences in color.

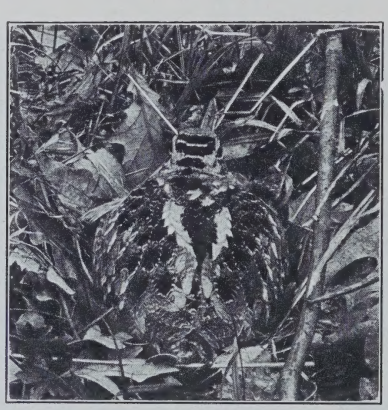

FIG. 215.—Woodcock on the nest, an illustration of protective coloration. (Photograph by Guy A. Bailey.)

Color is undoubtedly of value to animals. To what extent their protective colors are helpful it is difficult to specify. As the higher types of animals range over a widely varying landscape there cannot be much protection. On the other hand, if the color actually does partly conceal an animal at such a critical period as during the breeding season then it is of real benefit not only to the individual but to the race. Such colors as have just been described are believed to be preserved in nature by the action of natural selection (page 282).

The benefits derived by animals from possessing a coloration that

enables them to be concealed or to secure their food depend on a correspondence in color between the animal and its environment. Mimicry, on the other hand, is a form of resemblance between two different animals. Wallace was one of the first to work out these relationships in any detail, and the following quotation is from him: "This term mimicry has been given to a form of protective resemblance in which one species so closely resembles another in external form and coloring as to be mistaken for it, although the two may not be really allied and often belong to distinct families or orders." Wallace lays down constant conditions under which mimicry takes place: (1) That the imitative species occur in the same area and occupy the very same station as the imitated. (2) That the imitators are always the more defenceless. (3) That the imitators are always less numerous. (4) That the imitators differ from the bulk of their allies. (5) That the imitation, however minute, is external and visible only, never extending to internal characters or to such as do not affect the external appearance.

The general facts of mimicry are as well established as any phase of coloration in animals. Some of the advocates of mimicry, especially the earlier workers, carried their resemblances too far, as subsequent studies proved, but there is now on record a large amount of valuable evidence in support of the hypothesis of mimicry.

REFERENCES.

BEDDARD: Animal Coloration.
HEILPRIN: Geographical Distribution of Animals.
JORDAN and KELLOGG: Animal Life, Chapters XIV, XV, XVIII.
LULL: Organic Evolution, Chapters IV, V, VI.
NEWBIGIN: Color in Nature.
ROMANES: Darwin and after Darwin.
SCOTT: The Theory of Evolution, Chapter V.
WALLACE: Darwinism, Chapters VIII to XII.
WALLACE: The Geographical Distribution of Animals.
POULTON: The Color of Animals.

CHAPTER XXVI.

SOME ADAPTIVE HABITS.

In the preceding chapter various adaptations were discussed, but none of these touched on the adaptations in which the social unit is modified nor on that peculiar adaptive habit known as parasitism. Numerous examples are known which illustrate the successive steps through which organisms have passed in becoming adjusted to these unusual relations, all of which are examples of secondary adjustments and properly described as *acquired habits.*

Modifications of the Social Unit.—In all of the higher animals there is coöperation and the pair, male and female, are the social unit. This pairing springs from the necessity in all sexual animals of fertilization in order to insure the perpetuation of the species. In fertilization some provision of either habit or structure is utilized in bringing to pass the union of the sperm with the ovum. We have come to accept this as the normal condition in animals, simply because it is the relation in the majority of them. Any departure from this is regarded as a special modification. Colony, community, and gregariousness are special terms illustrating a departure from the social unit.

(*a*) *Colony.*—The colonial Vorticellidæ and Hydrozoa, both have several individuals united by a common stalk. (Fig. 216.) These individuals are of two kinds, feeding and sexual. In Hydractinia two protective individuals are added, thus giving a complex colony of a high degree of specialization. This form of dependence was not continued into the higher forms of life.

(*b*) *Community Life.*—The social life of the honey bee (page 228) is an illustration of this specialized social habit. A higher degree of community life is found among some of the ants, where, in addition to the sexless worker, there are to be found soldiers and slaves. An interesting account of the complicated family life of the ants is found in Chapters XIX to XXVII of Wheeler's book on Ants.

(*c*) *Gregariousness.*—Among the birds and mammals the habit of forming flocks for all or part of the year is common. In some of the flocks a form of polygamy exists, the king of the flock killing the

other males in combat. Such a collection of animals is obviously one in which protection against enemies is the dominant reason for the association (Figs. 217 and 218).

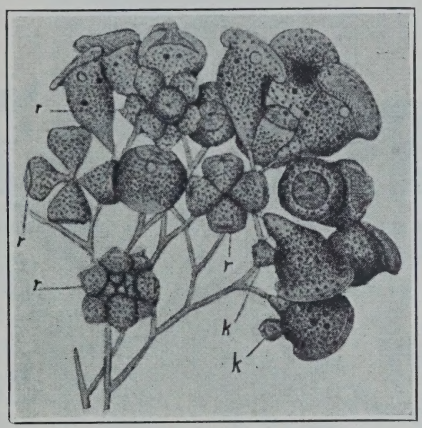

FIG. 216.—Epistylis umbellaria. *r*, formation of microgametes; *k*, the microgamete fusing with the macrogamete. (From Hertwig, after Greff.)

Each group exhibits a form of specialization and the species would become extinct if these relations were prohibited. But any compre-

FIG. 217.—A harem on Gorbatch rookery; the bull with many cows and newborn pups, July, 1914. Each harem consists of a single bull and from 20 to 100 cows. (Parker.)

hensive review of the special social habits indicates that these are extreme examples and that many intermediate stages between the

pair of animals and the community exist. They are thus to be regarded as representing the climax of coöperative social habits.

FIG. 218.—Murres or arries on Walrus Island, July 16, 1914. (Osgood, Preble and Parker, Bulletin of the Bureau of Fisheries.)

Symbiosis.—*This is a relation where two dissimilar organisms live together for their mutual benefit,* conveniently described by the term symbiosis, which simply means living together. These relations occur between animal and plant, animal and animal, and plant and plant. For example, the lichen is a simple grayish plant growing on fences and stones (Fig. 219). If a botanist is asked to classify the lichen he usually hesitates, because the plant consists really of two distinct plants that have become so intimately associated that neither lives alone (Fig. 220). The grayish color is due to the effect of the whitish fungi which grow over and around some green cells. The fungous elements belong to the same class of plants as the mushrooms, while the green cells are intimately related to the plant that often gives a greenish tint to the bark of trees and to the plants growing in ponds, and known as pond scum. These two distinct plants live intimately

FIG. 219.—Photograph of lichen growing on a tree.

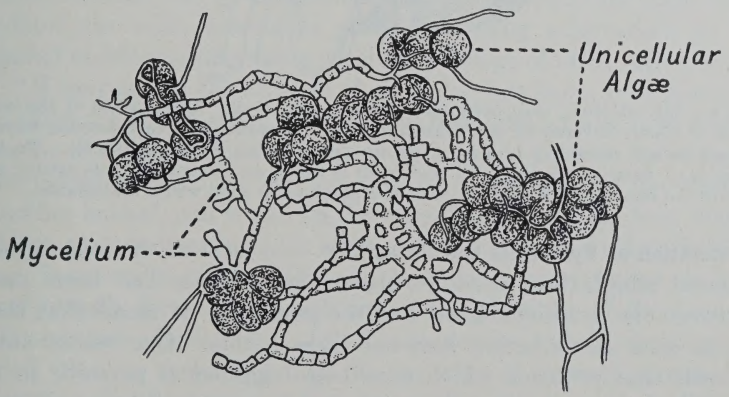

FIG. 220.—Section of the lichen-physica-paratina, to show symbiotic relationship between two plants. (Redrawn from Bounier.)

associated, and it is difficult to see how the relation is harmful to either, and, in fact, it is regarded as decidedly beneficial. The second example is where two animals live together. Review conditions in Hydra, p. 197. The hermit crab, a form related to the lobster, protects itself by occupying empty snail shells, into which it backs in case of danger (Fig. 221). In the Mediterranean Sea there is frequently found on such a snail shell a large sea-anemone which is permanently attached to it. The sea-anemone belongs with the corals, jelly-fish and hydras—a much simpler and lower class of animals than the crabs. The sea-anemones are provided with numerous stinging organs that have a paralyzing effect which renders them inedible. Now the hermit crab is eaten by predaceous fish, but not when it carries the sea-anemone around on its back. The sea-anemone gathers its food from the water, but it is stationary in habit and can secure only what the water brings to it. The hermit crab moves about from place to place, thus enabling the sea-anemone to secure food more easily. Such are some of the obvious reciprocal benefits.

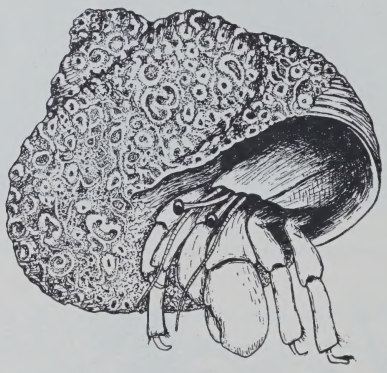

FIG. 221.—Hermit crab occupying a fossil snail shell. The surface of the snail shell is mostly covered by the incrustations of numerous small tube-forming worms. These hermit crabs live in holes near the water on the Bermuda Islands. To this species of hermit crab the fossil snail shell is but a convenient and safe retreat and serves the same purpose that the shell of a present-day snail would if available.

Relation of Symbiosis and Parasitism.—In most discussions of these general adaptations a rather sharp classification has been made between the symbiotic habit and the parasitic. It seems that there is no clear demarcation between these habits. One recent study reveals that protozoa which were long regarded as parasitic in the intestinal tract of certain termites are in part symbiotic.[1] Certain

[1] Symbiosis between Termites and Their Intestinal Protozoa. L. R. Cleveland, Proc. National Academy of Sciences, 1923. **9**, 424.

species of the wood-feeding termites contain wood-ingesting protozoans. Careful experiments have been conducted on these animals and it is probable that the protozoa and not the termites have the ability to digest the wood, because the wood-ingesting termites die when these protozoa are removed from the digestive tract. Here are animals living on the food of the termite similar to the tapeworm but as they do this the wood is partly digested for the termites which have come to depend on the protozoa to bring about these changes.

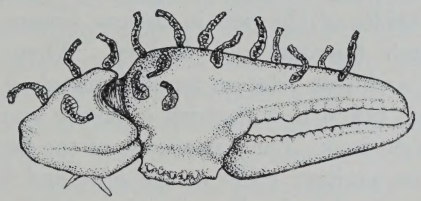

FIG. 222.—These small worms are found attached to the exoskeleton of the crayfish. They feed upon unicellular algæ and diatomes, so do not derive any food from their host. In this instance these worms, *Branchiobdella pulcherrima* and *B. instabilia*, cannot be regarded as parasitic nor are they symbiotic in the usual meaning of this relationship. Drawn from material collected in Lake Clear, Adirondacks.

Parasitism *is the relation where organisms live on or in other organisms and this is not mutually beneficial.*

Weismann clearly expresses the extent and significance of the habit known as Parasitism: "The most convincing proof of the organism's power of adaptation is to be found in the fact that the possibility of living parasitically within other animals is taken advantage of in the fullest manner, and by the most diverse groups, and that their bodies exhibit the most marvelous and far-reaching adaptations to the special conditions prevailing within the bodies of other animals.

"If we consider the number of obstacles that have to be overcome in existence within other animals, and how difficult and how much a matter of chance it must be even to reach such a place as, for instance, the intestine, the liver, the lungs, or even the brain or the blood of another animal, and when, on the other hand, we know how exactly things are now regulated for every parasitic species so that its existence is secured notwithstanding its dependence upon chance, we must undoubtedly form a high estimate of the plasticity of the forms of life and their adaptability. And this impression will only be strengthened when we remember that the majority of internal parasites do not pass directly from one host to another, but do so only through their descendants, and that these descendants too, must undergo the

most far-reaching and often unexpected adaptations in relation to their distribution, their penetration into a new host, and their migrations and change of form within it, if the existence of the species is to be secured."

Let us now examine some of the biological problems presented by the acquired habit of parasitism. These are summarized under Classification, Extent, Alternate hosts, Why parasites are sometimes very numerous, Degeneration and Experimental Degeneration.

The term "parasitism" was first employed to describe those who sat around the tables of the rich in ancient Greece receiving their invitation through fawning and flattery. When the word was used to describe a similar relation among animals it was applied to animals that have taken to a thievish existence as unbidden guests in or on other organisms. Our knowledge of the facts of parasitism goes back into the sanitary codes of the Jews and Egyptians which declared as unclean such animals as the pig, rabbit and dog, animals now known to be especially infested with parasites, and it is only within recent years that our sanitary laws have made pork a clean meat. During the middle ages the school men perplexed themselves with quaint hypotheses as to the time and place of the introduction of parasites into man. The idea that life could spring suddenly into existence was a fruitful suggestion for their origin, and it was not until the eighteenth century, when the life-history of one of the flesh-eating flies was completely worked out, that scientific men began to suggest that parasites arose from free-living animals. This discovery led to a truer knowledge of the origin of parasites, and from then on until today there is not a parasite known that cannot be traced in origin to some antecedent life.

Classification of Parasites.—Biologists would be glad if they could work out an exact classification for the plants and animals that lead a parasitic life, but this is impracticable because the adaptations that have taken place do not follow any regular law, as the following shows: Animals like horse-flies and mosquitoes, which come and go, may be termed *temporary;* while the bird-lice which pass their entire life on the bird are called *permanent.* The fleas, ticks, dodders, mistletoes and others confine their relation to the outside of their host, and the term *external* is applied; while the tape-worm of cat, dog or man is entirely within the body, and so should be called *internal.* The life history affords another method of classification. The leech is parasitic in the *adult* while the larva of the fresh-water clam always passes a part of its development

encysted in the gills of some fish, typifying a class of animals parasitic only during their *larval* existence. From this same standpoint there are those animals also which either *complete* their *life* in *one host*, such as the pup worms found in young seals, or those that demand *several* hosts. Of this latter class is the organism malaria, which spends part of its life in the blood of man and the remainder in the body of the anopheles mosquito. Or the malarial parasite may be classified as one that is dependent for its existence upon its hosts and thus termed an *obligatory* parasite; while any parasite which temporarily lives within or upon a host and can exist without utilizing the parasitic habit a part of the time is called a *facultative* parasite. The parasitic bacteria belong in the main under this latter term. The effect on the parasite affords still another form of classification. Some parasites, like the leech, mosquito or trichinella, show very little effect as a result of this habit; while the great majority are permanently and noticeably degenerated as a result of their mode of living.

Extent of Parasitism.[1]—It is a well-known fact that all of the larger animals harbor or may harbor many parasites, but as soon as careful studies are made the smaller animals also are found to be parasitized, even the protozoa. One recent expert says that "it is not a too sweeping generalization to state that every living thing large enough to contain another living thing is subject to invasion by parasites. The protozoa, themselves single cells, often play the part of host to smaller protozoan cells, and parasites often infect the nucleus of ameba, paramecium, vorticella and other types." No less than 69 species of parasitic worms have been found in man alone. It is difficult to make the word parasite convey an exact meaning, for we know that many trees harbor hundreds of insects; that the fly, mosquito and others occasionally bite us. From the fly to the tick is but a short step, and the tick is surely a parasite. The sheep in the pasture feeding upon the grass and the fox killing mice for her young are in a broad sense living on other living things. These cases are not regarded as parasitism, although the habit is essentially the same. The word parasite is best limited to such plants and animals as literally take up their residence for a time upon some other form of life, which is the host. This means that the parasite is always smaller than the host, although it may be a higher organism. In most instances parasites are simpler in structure than their host, as the tape-worm in dog or the ameba in man.

[1] Outline of Medical Zoölogy gives in detail the extent of human parasitism. (By Hegner.)

Alternate Hosts.—It is impossible in the limits of this book to do more than illustrate the most conspicuous habits of parasitic organisms. Parasites that are parasitic in the *larval stage only* are well illustrated by the habits of the fresh-water clams. When the embryos of these clams have passed through the segmentation stages they grow into a form known as the *glochidium* (Fig. 225). This is a stage in the development of the clam quite unlike the adult. It bears the same relation to the clam that the tadpole does to the

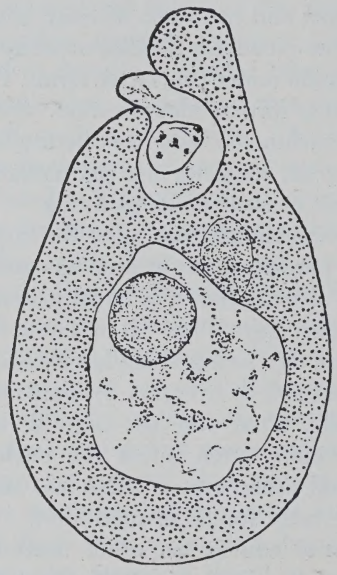

FIG. 223

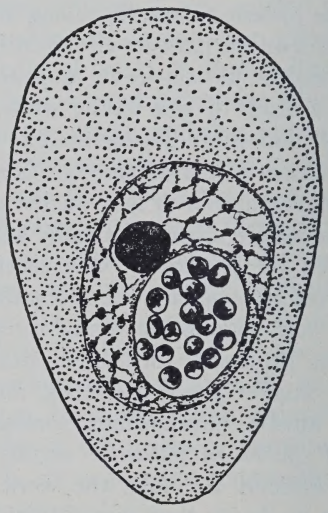

FIG. 224

FIGS. 223 and 224.—Among the strange places that parasites are found none is more unusual than one of the sporozoan parasites, haplosporidium mytilovum, that passes part of its life history in the ovum of a mussel, the parasite enters the cytoplasm, 224, and either here or in the nucleus, 225, develops spores. (From Field Bull. of Bureau of Fisheries, vol. 38.)

frog. When the glochidia are set free in the water they sink to the bottom. They are entirely incapable of locomotion, although the adductor muscle causes the valves to close frequently, and in response to mechanical stimuli the valves close firmly and remain closed. As the fins of a fish brush over the hooked glochidia they become attached to the fish. Here they remain as parasites from two to ten weeks, the length of time depending upon the species of clam. The glochidia which do not have hooks become attached to the gills

(Fig. 226), entering through the mouth of the fish as water is taken in for respiration. During the time that the glochidia remain as parasites on the fish they are metamorphosed into small clams. Unless the glochidia become attached to the fish they die.[1] A moderate-sized fish may carry successfully from one to two thousand of these parasitic glochidia. The fresh-water clams of several species

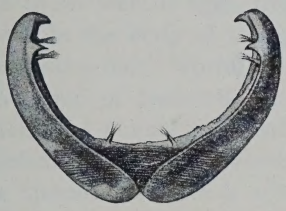

FIG. 225.—Axe-head glochidium of the clam, Lampsilis (*Protera alata*), anterior end view. In the larval stage the glochidium of certain fresh-water molluscs lives from nine to thirty-six days as a parasite in fish, and this is a necessary stage in its life history. (Le Fevre and Curtis.)

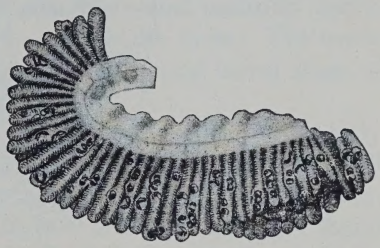

FIG. 226.—Gill of yellow perch infected with glochidia of the clam (*Lampsilis ligamentina*), showing distribution upon the gill as a whole and the appearance of the cysts. They are also found on the fins. (Le Fevre and Curtis.)

thus illustrate a specialized habit in which fish have become necessary to the clam's growth to maturity. Immunity to the glochidial parasite, Lampsilis luteola, may be acquired by the black bass in two or more infections and the parasites are sloughed within two or three days.

FIG. 227.—Second larval stage of "horse-hair" worm in body of grasshopper.

A similar parasitic habit is evident in the "horse-hair" worm shown in the body of the grasshopper (Fig. 227). These worms are not parasitic when adult and are commonly seen in springs, watering troughs, etc. The eggs hatch into a small larval stage that usually

[1] Le Fevre and Curtis: Studies on the Reproduction and Artificial Propagation of Fresh-water Mussels, Bull. Bureau Fisheries, 1910, xxx, Document No. 756.

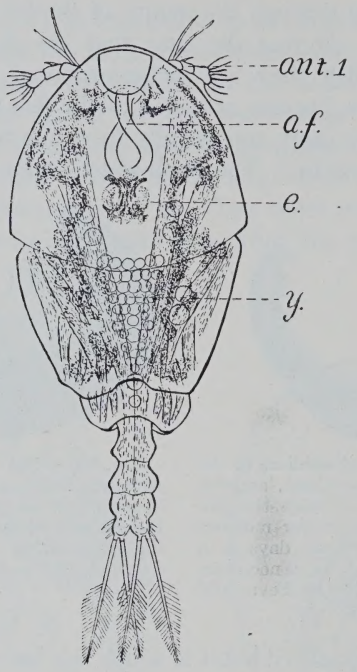

FIG. 228.—*Salminicola edwardsii.* Dorsal view, free-swimming stage. × 173.5. *a.f.*, attachment filament; *ant. 1*, first antennæ; *e*, x-shaped eye; *y*, yolk. (Fasten, Journal of Animal Behavior.)

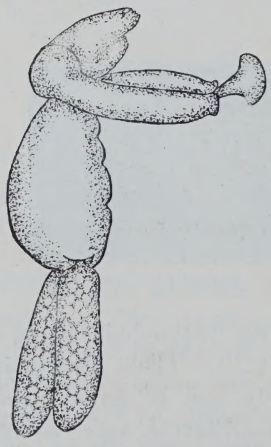

FIG. 229.—Adult fish-louse, *Salminicola edwardsii.* Compare the structures present with those in Fig. 226. (Redrawn from C. B. Wilson.)

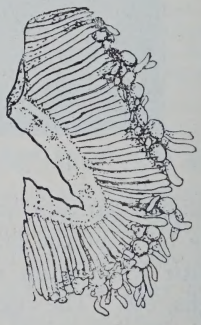

FIG. 230.—"Fish-lice" attached to gill of fish.

enters the body of some insect. After passing through certain changes it is set free in the water. This condition is known as the second larval stage. The second larval stage enters the body of an insect or fish, where it continues to live until it comes to look much like the adult worm; but before the adult stage is reached this second larval stage leaves the body of its host and becomes a free-swimming worm in the water. Here it quickly reaches sexual maturity and is able to set free its eggs, thus completing the life cycle. The worm shown in the body of the grasshopper is the second larval stage of the "horse-hair" worm.

A group of parasites familiarly known as "fish-lice" are widely distributed among both salt- and fresh-water fish. There are 136 different species, all of which are parasitic during their *adult life only*. The species *Salminicola edwardsii* is very common, although found exclusively on the brook trout. It lives attached to the fins and gills of the fish (Fig. 230). In its adult stage the female undergoes a great deal of degeneration (Fig. 229). During the larval stage the young animal swims actively about and possesses the usual organs found in the group of crustacean animals to which it belongs (Fig. 227). The specialized habits of the "fish-lice" are the reverse of the clam and the "horse-hair" worms, but the fish has come to be just as necessary to the fish-lice as it is to the clam. These two parasites also illustrate the effect of parasitism upon the parasite, for the worms show practically no change, while the fish-lice undergo a large amount of degeneration.

The following study presents a phase of parasitism that is very important not only because it illustrates the *complicated life history* of certain parasites, but also because it indicates how difficult it is to prevent the spread of such parasites.

The organism which causes the white-pine blister rust[1] lives in one stage upon the pine and in the other on the leaves of currant or gooseberry bushes. It is a plant that belongs to the fungus group known by the technical name of *Cronartium ribicola*. Like most fungous plants there are produced spores which are carried by the wind. When the spores of a certain stage in the life of this parasite fall upon the white pine they begin to grow in the bark. Here they may live from one to six years with no external sign of their presence. The first indication of the presence of these parasites is the swelling of the bark at the point of infection. Fruiting bodies push their way through the swollen tissue. As these ripen numerous spores like bright yellow powder

[1] Perley Spaulding: The White-Pine Blister Rust, Farmers' Bulletin, No. 742.

are discharged. Each spore is capable of reproducing the disease but they cannot grow upon the white pine. To distinguish these spores

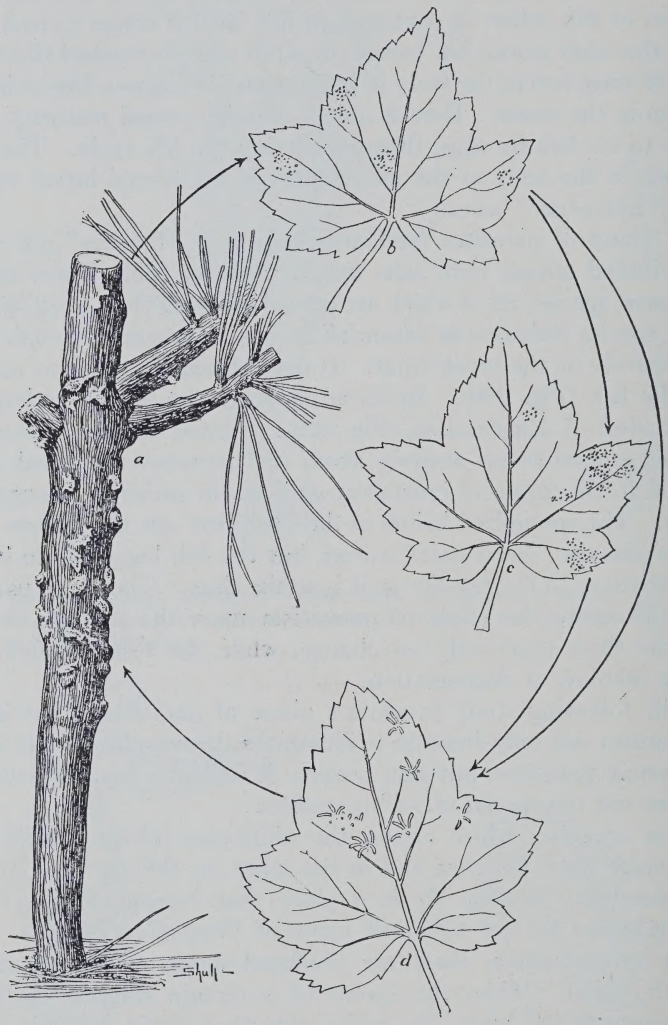

FIG. 231.—Diagram indicating the life circuit of the causal fungus of the white-pine blister rust. *a*, blisters on pine in May and early June, from which the disease spreads to currant or gooseberry leaves and produces the early summer stage, *b*, thence it may spread to another currant leaf and produce there a second crop of the early summer stage, *c*, or it may produce the late summer stage, *d*, in this stage; in the fall it infects neighboring white pines, which may or may not include the pine (*a*) which bore the blisters that started the outbreak the preceding spring. (Spaulding, United States Department of Agriculture.)

from a second kind of spore they are called *peridermium* spores (Fig. 231).

The peridermium spores are blown about by the wind, and if one falls upon the leaf of a currant or gooseberry plant it is able to attack that leaf. This small spore "sends its root-like germ tube into the soft tissues of the currant leaf, and there it spreads within the leaf tissues until it has attained a certain amount of strength." In about two weeks there appear on the upper side of the currant leaf tiny masses, hardly larger than a pin-head, of fine, orange-yellow powder. These new spores are quite distinct from the peridermium spores and hence are called *uredospores*.

The uredospores may be called the repeating stage, as these spores can only reinfect currant or gooseberry leaves. This they may go on doing every two weeks from the latter part of July until the leaves drop off in the fall. At this time a third form of spore is grown which appears in the same spots that have been earlier producing uredospores. "The new form appears as a group of three to ten of short, stout threads, not over a quarter of an inch in length, which usually are in small circles. Upon these threads are produced spores of another distinct form. These are the *teliospores*."

The teliospores cannot repeat their development on the currant or gooseberry leaves but must fall upon the bark of young white pines. These spores can germinate, penetrate the bark and grow in the inner layers. The life cycle is complete. The presence of numerous wild currant bushes in forests of white pine is a source of real danger.

The white-pine blister rust illustrates what is known as the alternation of hosts in the life cycle of parasites, which should not be confused with alternation of generations in hydroids, for example (page 190).

Why are Parasites Sometimes Very Numerous?—The student will find an answer to his question, "Why are parasites more numerous in certain parts of the country or during certain years?" in the following explanation of the life history of the spring grain aphis. In order to answer this question accurately it is necessary to know in detail the habits of the animal about which the question is asked. The explanation, however, is to be found in the relation which certain conditions, such as food, temperature, time of breeding and enemies, bear to each other. The following, then, is a typical scientific explanation of the abundance or scarcity of parasites. "The spring grain aphis (*Toxoptera graminum*) is present every year in greater

or less abundance and is kept under control by its natural enemies, more especially by a tiny black and brownish four-winged fly (*Lysiplebus tritici*). The aphis gives birth to young from spring to fall, but during mild winter weather young are born as long as such weather continues while the parasite remains dormant. The aphis begins to breed whenever the temperature rises to 45° or 50° F. during the day, while for the parasite it must be at least 10° warmer. Under normal weather conditions during winter and spring the aphis starts in the spring from the eggs (winter eggs), and there are enough parasites which have wintered over in the bodies of the aphis and emerged therefrom to destroy so many of this aphis that it cannot increase rapidly enough to become injurious; consequently there is no trouble. But there comes a winter during which the temperature is warm enough to enable the aphis to breed continuously, and it thus becomes abundant by spring. If the weather turns cold during the winter the pest ceases to breed and serious depredations are averted; but if, as is more often the case, a cold, backward spring follows an abnormally warm winter then the pest continues to breed while its enemies remain inactive, and the result is that the former becomes so enormously abundant that wheat and oats are destroyed over large sections of the country before the parasite can increase sufficiently to overcome it." (Webster.)

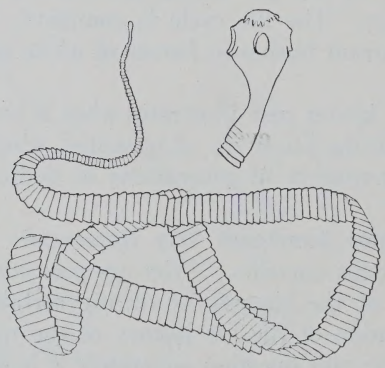

FIG. 232.—Diagram of tapeworm.

Degeneration.—The two best known examples of degeneration are the tapeworm, Fig. 232, and Sacculina, Fig. 233.

Tapeworms.—These animals do not have a digestive system as they are bathed in the digested foods of their hosts. Each segment of the

body, Fig. 232, is a rather complete unit in itself. The anterior end is termed a scolex and has suckers or hooks for clinging to the wall of the intestine. Each segment, a proglottid, arises asexually from the scolex. The tapeworm is not only an example of degeneration, but also of alternate hosts. The common beef tapeworm is adult in the intestine of man and the eggs are eaten by cattle. In the intestine of the cow, these eggs hatch into a larva which bores its way into the muscles or liver. After three months, this larva may then infect man.

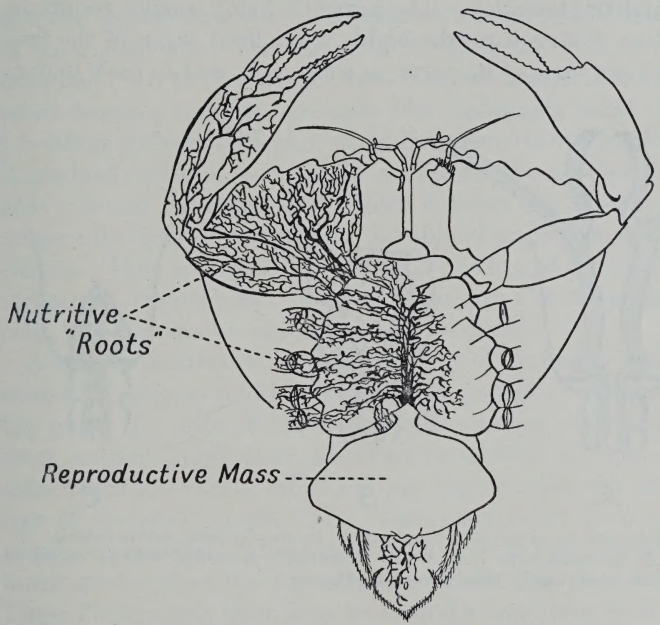

FIG. 233.—Diagram of sacculina attached to a crab. This is the adult stage.

Sacculina.—This parasite is a member of the family of barnacles, but no one would be able to hazard a guess as to its relationships if the adult stage only were known. When the eggs hatch, the familiar Nauplius-larva stage is shown, with three pairs of appendages, a food canal and a median eye. These larvæ attach themselves by means of their first pair of feelers to young crabs. The head is cast off and all of the structures that belong to the head are lost, and a minute sack only remains as the representative of the Nauplius-larva. Soon the parasite makes its way through the external skeleton of the young crab, near the base of the legs and the body begins to creep out of the

sack and form a number of foot-like outgrowths. (See Fig. 233). It lives for possibly three years, interfering with the growth of the host and destroying the reproductive organs. In the meantime, it has spread through the body of the host crab. When the adult Sacculina is dissected it is shown to be in an extreme state of degeneration. There is nothing comparable to an alimentary canal and only a very rudimentary nervous system, the body really consisting of reproductive organs only. This is an extreme case of the effect of parasitism.

Experimental Degeneration.—The parasitic habit usually results in a simplification of structure; the highly specialized organ of the free living forms loses some of its parts, in short, it is said to have under-

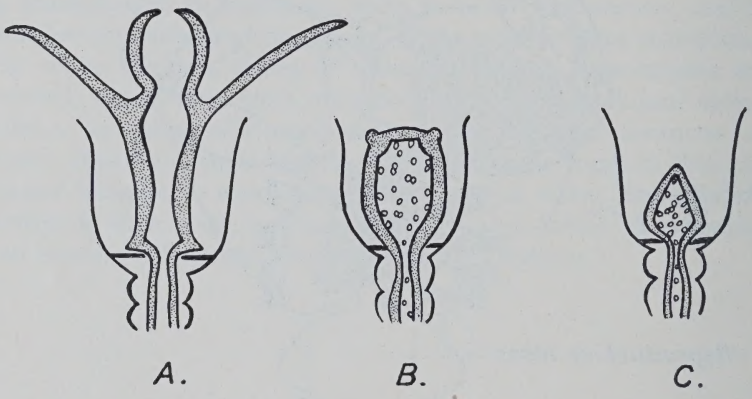

FIG. 234.—Diagram to show dedifferentiation in the hydroid campanularia. *A*, normal zoöid; *B*, tentacles have been nearly absorbed. Resorbed cells in cavity of hydranth; *C*, still later stage. (Redrawn from Huxley.)

gone degeneration. While this is a frequent result, quite the reverse may be true as indicated in the development of specialized hooks or suckers on the anterior end of many parasitic worms. (Fig. 232). We have often wondered whether complicated organs really did degenerate because of altered habits and changes in the environment.

During recent years a great deal of experimental work has been done on animals to determine their reaction to toxic products introduced into their environment. Several researches have been carried out on the hydroids which are very sensitive to changes, even showing the loss of tentacles when brought into the laboratory and confined in glass dishes. Huxley has recently observed the loss of tentacles, and even the entire hydranth in Obelia and Campanularia (Fig. 234).

This process is termed *dedifferentiation* because there is a lack of agreement as to the exact cells from which the newly formed parts develop. A second illustration is the Ascidian, Clavellina. This is a small animal living in a colony and each individual is about an inch long. It lives in the sea and is sedentary in its habit after it reaches the adult form. The water is carried into the pharynx where the food is strained out. Now when this animal is placed in unfavorable conditions, as in a small aquarium, and the water is allowed to grow stale, the opening through which the water enters the body is closed and the animal shrinks until it becomes a small mass about one-tenth of its original size. The organs of the body are reduced to shapeless bags and even the cells in the tissues of the organs lose some of their adult features and become more like embryonic cells. If then the Clavellina is placed in clean, fresh water, where there is good circulation, it gradually returns to its adult condition. Because of the unfavorable external relations, the balance between the several organs has apparently been disturbed and the animal undergoes marked degeneration. Here is a clear illustration of the loss of certain of the adult structural features not only of organs in Clavellina but also the cells, and this can be experimentally produced.

A similar illustration is found in many of the insects which undergo complete metamorphosis. During the period of reorganization in the pupa, the cells of the body wall, muscles and even intestinal tract in many break down and there remains an unorganized mass of cells which are slowly reformed into the muscles, the skin, and the legs of the adult insect. This takes place every time one of these insects is produced. The degree and extent of reorganization here is much greater than the degeneration which takes place in parasitism. These illustrations then, help us to understand how such changes as degeneration may have taken place in plants and animals. We may interpret the first two as experimental degeneration; and the last as one of Nature's most striking experiments in altering and changing the organs of animals. In the light of such facts, the explanation that parasitism is responsible for the degeneration present in such animals is reasonable.

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CHAPTER XXVII.

ADAPTATION AND DISEASE.

Disease-causing organisms are usually parasitic: but whatever their relationship, there is a scientific explanation for the sequence of events that characterizes all such abnormal conditions. As we

Fig. 235.—Photograph of the lateral aspect of a humerus from the fossil known as Mosasaur from the cretaceous rocks of Kansas. The diseased condition is known as osteoperiostitis. The disease is a condition that has existed in organisms from the earliest times. Even Pott's disease which is of tuberculous origin has been identified in an Egyptian mummy of about 1000 B. C. (Photograph furnished by Roy L. Moodie.)

review this interesting adaptation, we should keep in mind (1) that in all instances the disease-producing agent is a natural product;

(2) that the extent of the derangement and the resistance of the protoplasm to the poisons is a phase of adaptation.

We shall review first the principles involved in diseases caused by such non-parasitic organisms as the Rattlesnake and Amanita; then the parasitic disease of Malaria, Tapeworms, Mosaic disease, and the Filterable viruses. Following these, the problem of the Bacterial parasites and their relation to disease will be taken up. This naturally carries us into the problems of Immunity, Vaccination and Disease carriers.

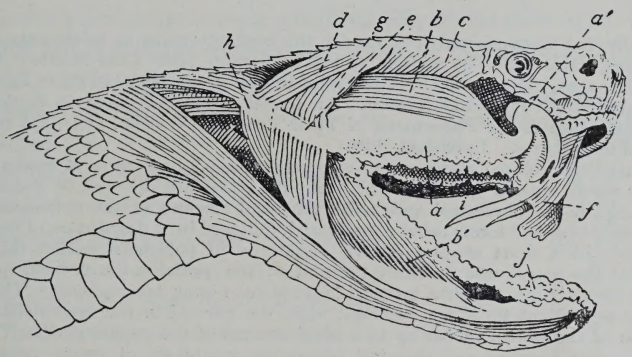


FIG. 236.—Poison apparatus of rattlesnake, venom gland and muscles. Lateral view. *a*, venom gland; *a'*, venom duct; *b*, anterior temporal muscle; *b'*, mandibular portion of same; *c*, posterior temporal muscle; *d*, digastricus muscle; *e*, posterior ligament of gland; *f*, sheath of fang; *g*, middle temporal muscle; *h*, external pterygoid muscle; *i*, maxillary salivary gland; *j*, mandibular salivary gland. (From Steineger, after Duvernoy.)

Rattlesnakes.—The rattlesnakes all possess a gland, located on both sides of the head and just below and behind the eye, which secretes a poison. From the anterior end of the poison gland extends a duct that opens at the base of the fang. The following account will serve to illustrate how the poison acts upon man: One of the attendants at the National Zoölogical Park was bitten, on August 17, by a diamond rattler (*Crotalus adamanteus*) on the middle finger of the left hand, proximal phalanx. The wound was immediately sucked and within fifteen minutes cauterized with a 1 per cent solution of potassium permanganate. He was removed to a hospital where the following changes were found to be taking place: On admission the blood examination was: red blood cells, 4,600,000; white blood cells, 14,440; hemoglobin 95 per cent. Eighteen hours after being bitten the blood examination was: red blood cells, 4,000,000;

white blood cells 16,000; hemoglobin, 75 per cent. On the fourth day the blood count was: red blood cells, 2,800,000; white blood cells, 14,000; hemoglobin, 60 per cent. The sixth day showed the lowest condition of the blood: red blood cells, 2,000,000; white blood cells, 12,000; hemoglobin, 45 per cent. After this date the patient began to recover and the cells of the blood gradually returned toward the normal, although six weeks after the snake had bitten him his blood count was only red, 3,588,000; white, 9000; hemoglobin, 87 per cent.[1]

The following Carnegie publications are the best references to rattlesnakes:

NOGUCHI, HIDEYO: The Action of Snake Venom upon Cold-blooded Animals, Octavo, 16 pages. (Embodied in Publication No. 111.) Published 1904. Price $0.25.

NOGUCHI, HIDEYO: Snake Venom: An Investigation of Venomous Snakes, with Special Reference to the Phenomena of Their Venoms. Octavo, xvii+315 pages, 33 plates, 16 text figures. Published 1909.

Although this volume refers more especially to the phenomena of snake venom, it covers much broader ground. The first fifty pages are devoted to a descriptive and systematic morphological and a distributional account of the poisonous snakes of the world, over 300 forms being enumerated, followed by a description of the poison apparatus. In a short chapter on the phylogeny of poisonous snakes the author states that the poison was probably the first of the specialized structures to appear and that the elaborate, erectile, grooved fangs were of later development. The poison gland "is equivalent to, if not identical with, the parotid of the mammalia." The remainder of the work is given up to a consideration of the venom itself. There are chapters on its physical and chemical properties; symptoms of venom poisoning in man and in lower animals; and on the organism as a whole and upon specific organs and tissues, this latter subject being more fully treated than any other.

There follow chapters on artificial and natural immunity, with a technical discussion of antivenins. The final chapter, "Treatment of Snake Bites," contains a careful review of the various so-called antidotes, with a scientific testing of their value. The monograph ends with a bibliography of about 400 titles and an index.

LOEB, LEO, in collaboration with Carl L. Alsberg, Elizabeth Cooke, Ellen P. Corson-White, M. S. Fleisher, Henry Fox, T. S. Githens, Samuel Leopold, M. K. Meyers, M. E. Rehfuss, D. Rivas and Lucius Tuttle: The Venom of Heloferma. Octavo, vi+244 pages, 38 figures. Published 1913. Price $1.50.

This volume contains a collection of papers dealing with the morphology of the venom gland, the physical and chemical properties of the venom, the action of the venom on vertebrate and invertebrate animals as well as on certain cells and organs *in vitro*.

Amanita.—Every year there are cases of mushroom-poisoning which terminate fatally. In all of these serious cases the mushroom eaten is probably one of the amanita group. The general effect of the poison is to produce acute intestinal pains and a rise in the pulse and temperature, often accompanied by delirium. The following is taken from Ford's recent study of the poisons in fungi: "It has been shown

[1] The details of the case are given by Dr. C. S. White in Jour. Am. Med. Assn., 1910, vol. 52.

that the 'white' or 'deadly' *Amanita phalloides* contains a powerful hemolysin which acts upon a great variety of corpuscles, is destroyed by heating to 60° to 65° C. for half an hour and has the chemical composition of a glucoside containing C = 48.03, H = 6.08, N = 10.83, S = 1.94, O = 32.22. This substance, judging from its destruction by heat and its susceptibility to the action of artificial gastric juice, cannot be held responsible for the symptoms seen in poisoning with the fungus in man. The species apparently owes its toxicity to the amanite toxin. Five cubic centimeters of the extract of *Amanita phalloides* killed a guinea-pig weighing 385 grams overnight, the same amount killed another guinea-pig weighing 420 grams in four hours and a rabbit weighing 1035 grams succumbed within eighteen hours to a dose of this character.

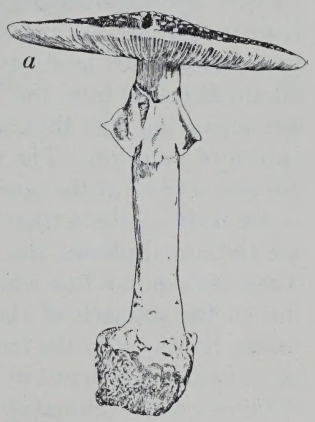


FIG. 237.—*Amanita phalloides.* (Rusby.)

The poison of the rattlesnake and the toxin of amanita are complex substances and already analyzed into two or more parts, and each of the components is responsible for a definite set of changes when introduced into man. In both instances the product is a normal growth of the organism.

The secretion from the poison gland of the rattlesnake is a poison which is a relatively simple chemical molecule that is broken down by digestion. This is the reason that it is safe to suck the wound caused by a poisonous snake. On the other hand the toxin found in amanita is a complex chemical molecule that is not destroyed by digestion. In a general way this serves to distinguish between organic poisons and toxins.

Malaria.—When this disease was first recognized it was thought to be associated with bad air and was therefore named malaria. In 1881 a French military doctor located in Algiers, Dr. Laveran, discovered in the blood of some malarial patients a new organism which he declared to be the cause of the disease. It was more than fifteen years after this discovery before definite information was available as to the source of this parasite in the human blood. The name *Plasmodium malaria* was given to this organism because of its supposed resemblance to some of the plasmodia-forming fungi.

Authorities differ as to the exact number of malarial parasites, but they all belong to the animal kingdom and are protozoa, class sporozoa, order hemosporidia (see page 128).

The malarial parasite is not able to complete its life-history in the one animal (reptile, bird or mammal) in which it first occurs, although it may live continuously for many months in the human body. The malarial plasmodium passes through a series of changes in the human body, as follows: The parasite penetrates a red blood corpuscle, where it increases in size until it nearly fills the blood cell (Plate III, Fig. 15). The time that it remains in the cell depends upon the kind of parasite, whether it be a one-day, a three-day, or a four-day form. At first the parasites are not very numerous, but after a few weeks their number is very great. As they all belong to the same original brood they reach maturity in the blood cells at the same time, and all are liberated from the blood cells at regular intervals. The fever accompanying this disease coincides with the liberation of a new swarm of parasites. The waste products of the parasite metabolism are also set free at the same time and assist in setting up disturbances in the body. After a time the parasites develop into two forms, which are the sexual phases, the *macrogametocytes* and the *microgametocytes.* These cells do not fuse while the parasite remains in the human blood but in the stomach of the anopheles mosquito. The fertilized cell makes its way into the lining epithelium of the intestine of the mosquito and comes to rest in the submucosa. Here it undergoes a series of divisions and ultimately gives rise to a stage known as a *sporozoite.* Some of these *sporozoites* make their way into the salivary glands and thence into the proboscis of the insect, from which they escape into the blood of man. Several thousands of sporozoites may be introduced in a single puncture of the mosquito's proboscis. The non-sexual forms of the parasite which are drawn into the stomach of the anopheles mosquito are destroyed. Should a culex mosquito suck the blood of a malarial patient all of the parasites are digested. And when an anopheles mosquito sucks the blood of a bird in which the organism *Plasmodium precox* (causing estivo-autumnal fever) occurs the parasites are all digested.

Malaria is a disease that is distributed all over the United States and especially in the South. It can occur only through the patients being bitten by an anopheles mosquito which has the *Plasmodium malaria* in its salivary glands. It is a serious disease in some sections, and in 1900, 14,909 persons distributed throughout the United States

PLATE III

FIG. 1

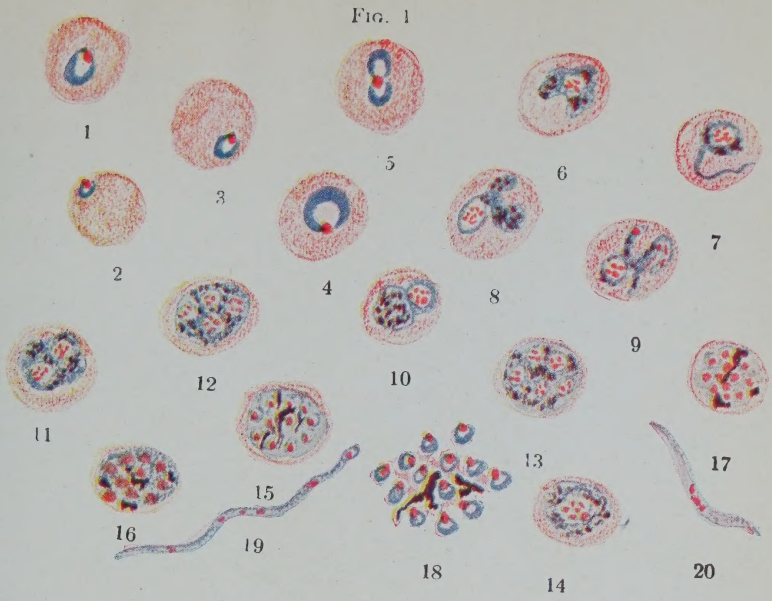
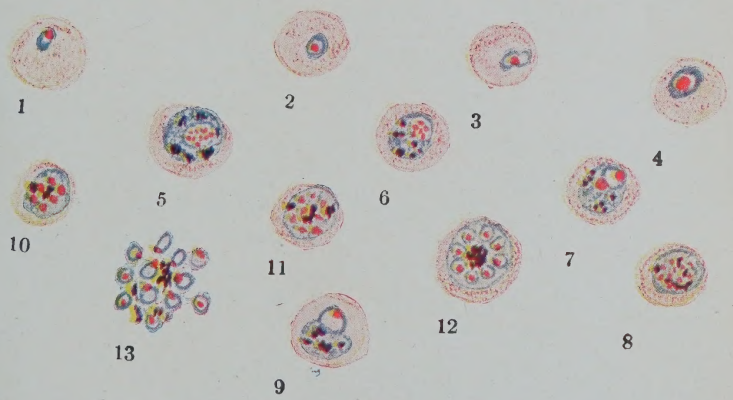


FIG. 2



CHARLES E. CRAIG, DEL.

Fig. 1.—Tertian Malarial Plasmodium. Stained by Oliver's Modification of Wright's Stain.

1 to 4. Ring forms of tertian parasite.
5. Ring form. (Conjugation form of Ewing.)
6 to 10. Pigmented organisms.
11 to 14. Nearly full-grown forms, showing diffusion of the chromatin.
15 to 17. Segmenting forms within red corpuscle.
18. Segmenting forms after destruction of red corpuscle.
19. Microgamete.
20. Sporozoite.

Fig. 2.—Quartan Malarial Plasmodium. Stained by Oliver's Modification of Wright's Stain.

1 to 4. Ring forms of quartan parasite.
5, 6, 7, 8, 9. Pigmented parasites.
10 to 12. Segmenting forms of quartan parasite.
13. Segmenting stage after destruction of red corpuscle.

NOTE.—Chromatin of nucleus stained red; protoplasm stained blue; vesicular portion of nucleus unstained.

died from it. There is no way of estimating the number who were incapacitated from working because of this disease. The writings of many of the Roman authors contain references to destructive epidemics of malaria, and the efforts to drain the deadly Campagna date back for many years. The first capital of Alabama, St. Stephens, which in 1810 was a thriving town, was literally wiped out of existence because of the prevalence of malaria. The present sanitary knowledge of malaria makes it entirely safe to live anywhere in the world if one simply protects himself from the bites of the anopheles mosquito by keeping behind a screen (19 meshes to the inch) after dark.

Tapeworms, Hook-worms and Others.—There are a number of highly developed animals that live as parasites mostly within the digestive canal in man and other animals. These are the well-known thread-worms, tapeworms, hook-worms and others. Their chief harm consists in either absorbing the nourishment taken by the host before it leaves the digestive canal or in the absorption of blood. The food being ready at hand in sufficient quantity, they have but to grow and reproduce until in some cases they become very numerous. It is not practical to make many general statements concerning this group of diseases because each animal has its own life-history and mode of entering the body. Some, like the tapeworm, have a complicated life-history, as already shown on page 345; while others, like the hook-worm, readily pass from man to man without an intermediate host. Hook-worm is an ancient and world-wide disease that belts the earth in a zone about 36° north to 30° south parallel. It is estimated that 900,000,000 people live in this belt. In some parts of this district, like Samoa, 70 per cent of the population, in southern China 75 per cent, in India from 60 to 80 per cent, in Dutch Guiana 90 per cent are found to harbor hook-worms. The economic loss from a disease so widespread is enormous. A physically sound coffee-picker in Porto Rico picks 500 to 600 measures a day; the hook-worm infected picker averages from 100 to 250 measures. The effects of this disease in stemming the progress of civilization in China, India, Egypt and other countries cannot be measured. The practical aspect of the question comes in determining the admission of immigrants from hook-worm countries. In 1911 a shipload of Indian coolies landed at San Francisco and when examined 90 per cent were found to be infected. A low class of immigrants with their lack of sanitary knowledge becomes a center from which such diseases spread. Dr. C. W. Stiles, the great authority on this disease, believes

that the sanitary privy in the non-sewered districts of the Gulf-Atlantic States and the wearing of shoes are the most important measures in preventing the hook-worm disease.

The Filterable Viruses.—At present there are some thirty diseases of human, plant and animal life which have been demonstrated to be due to organisms that can pass through a Berkefeld or Chamberland filter, and all of these are at present invisible with the highest powers of the microscope. Of the diseases which affect man the following may be mentioned: Foot-and-mouth disease, rabies, vaccinia, smallpox, yellow fever, dengue fever, trachoma, poliomyelitis, typhus fever, measles and scarlet fever. In most of these diseases the unknown germ is transmitted by some intermediate host, such as mosquito or body-louse. In the next few years much that is new will be added to our knowledge of this group of diseases.

Mosaic Disease of Plants.—During the past twenty years this very destructive disease has occupied the attention of phyto-pathologists. The increasing economic importance and wide distribution of the mosaic diseases has become so great that they constitute one of the major subjects for research in many institutions. These diseases are infectious being chiefly transmitted by insects. The plant lice are mainly responsible for the wide dissemination of the infectious material. The symptoms are similar in most plants which suggests a close relationship among the causal agents. The foliage becomes mottled into dark and light areas, there are a crinkling of the leaves and other distortional modifications, dwarfing and a marked reduction in the yield. This latter effect is alone the cause of a loss of many millions of dollars annually. Nelson[1] has just succeeded in finding numerous protozoa in the cells of plants showing the symptoms of mosaic disease. The complete life-history has not been worked out as the organism is small and variable in shape. It has been proved many times that the juice of plants can be passed through a bacterial filter and still cause this disease when injected into a healthy plant. The disease is given in this connection because it illustrates most forcibly the interrelationship that exists between these three dissimilar organisms, domestic plants such as beans, clover, tomatoes and others and the microscopic protozoans and insects. The part played by the insects has not been determined but the incomplete

[1] Ray Nelson: The Occurrence of Protozoa in Plants Affected with Mosaic and Related Diseases, Agric. Exp. Station, Michigan Agricultural College, Technical Bull. No. 58, 1922.

story suggests that the problem is similar to malaria where man is the host instead of the plant.

Animal Tumors.—Just how the various abnormal growths so frequently found in all of the higher animals are to be explained remains to be discovered. The recent studies on crown gall suggest that the cause may be due to microörganisms which our present technic does not reveal. This suggestion has much force in it when it is remembered that there are several diseases due to the so-called filterable viruses. These tumor-like growths are found in all of the vertebrates. A characteristic instance is shown in the kidney of the frog. This organ is usually regular in outline and of a dark red color. It is about 14 mm. long and 4 mm. wide. The kidneys

FIG. 238.—A normal-sized kidney in the frog (× 2x), showing the normal adrenal.

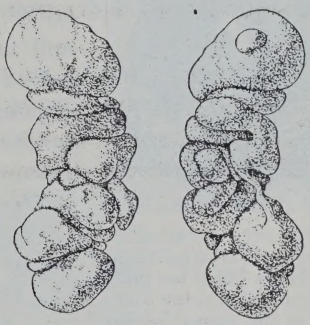


FIG. 239.—The dorsal and ventral view of the right kidney of the frog having the adrenal tumor.[1] × 2x.

shown in Fig. 239 were 21 mm. long and 8 mm. wide, and irregular in outline. The color of the fresh diseased kidney was whitish. Each kidney has a large number of lobes. The tumor growth is so extensive that the original kidney is revealed only in blotches and the ureter is carried around to the inner edge instead of being on the outer edge of the kidney.

Crown Gall.—Crown gall is a disease which occurs on a variety of plants and any part of the root or shoot is liable to attack. It consists of an irregular growth which frequently becomes larger than the root or shoot upon which it occurs. In this growing mass of cells the conducting tissues are imperfectly developed. The way that the

[1] Adrenal Tumors in Kidney of the Frog, Anat. Anz., 1905, Bd. **26**, No. 24.

cells grow and their manner of dividing tend to place this disease quite apart from the usual diseases in plants, locating it in the category of the true tumors; it is believed by Smith that the conditions are similar to animal tumors.[1]

FIG. 240.—A natural infection of crown gall in the hothouse which has probably resulted in the transfer of the germs by way of the gardener's hose in watering. (E. F. Smith.)

The cause of this disease has been an unsolved problem until the recent work of Smith and others. The successive steps employed in demonstrating that crown gall is due to a definite organism were the following: *First*, galls were crushed in beef broth, from which agar plate cultures were made, which were kept at temperatures varying from 20° to 30° C. The galls were thoroughly cleaned and modern antiseptic methods used. The *second* step was the finding of a definite organism to which the name *Bacterium tumefaciens* was given, growing on the agar-culture plates (Fig. 241).

The *third* step was to demonstrate that the bacteria isolated on the agar plates would cause a similar growth when introduced into the tissues of a healthy plant. On June 1 inoculations were made into the stem of young healthy daisy plants growing in the pathological greenhouse. On June 18 a distinct elevation was visible at each point where an inoculation had been made.

The *fourth* step was the study of these new galls and the finding of the same organisms present. The infectious nature of these organisms was proved by inoculating healthy plants which in turn produced galls. This method of conclusively proving that a given disease was caused by a given organism was formulated by Koch.

The bacteria causing this disease are located inside the cells, and it is the "stimulus of their presence which causes the cell to divide abnormally by throwing it out of balance." After the crown-gall tumor has been grown another series of changes begins. It seems

[1] Smith, Brown and Townsend: Crown Gall of Plants: Its Causes and Remedy, Bureau Plant Industry, Bull. No. 213. Smith, Brown and McCulloch: The Structure and Development of Crown Gall: A Plant Cancer, Bureau Plant Industry, Bull. No. 255. Smith, E. F.: Further Evidence that Crown Gall of Plants is Cancer, Science, June 23, 1916, p. 871.

that the soft tissues cannot be adequately nourished beyond a certain limit, and decay sets in. "A variety of saprophytic bacteria and fungi take part in disintegrating the overgrown tissues. Among these saprophytic bacteria there are several white forms closely

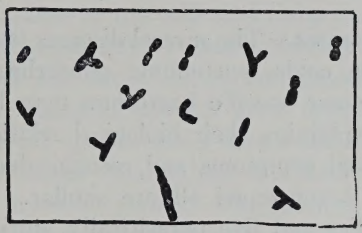


FIG. 241.—Bacterium tumefaciens. (E. F. Smith.)

resembling the gall organism as grown on agar-poured plates, dendritic white forms, green fluorescent species, yellow species, orange species, pink species, etc."

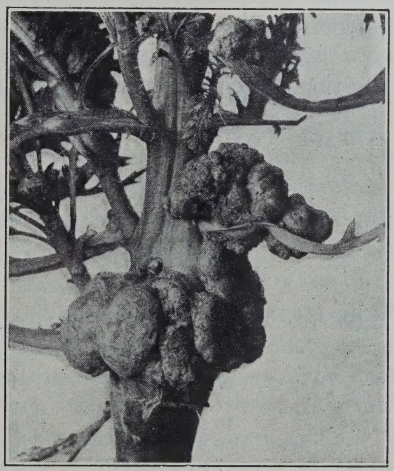


FIG. 242.—Plant inoculated November 26, 1907, and photographed March 8, 1908. (F. F. Smith.)

This disease serves to illustrate the method of determining the exact cause of a biological disease. The growth of the cells in crown gall is believed to be due to some stimulus produced by the bacteria as they live naturally, although as parasites within the cells. When

the original disease reaches its limit a number of disintegrating bacteria begin to live upon this abnormal growth, with the result that decay sets in and parts slough off, causing an open wound. The organisms which bring about all of these undesirable results are definite living things which have a specific structure and life history.

The Bacterial Diseases.—The several diseases (typhoid fever, tuberculosis, diphtheria, colds, pneumonia, gonorrhea, leprosy, tetanus, etc.), caused by some specific bacterium may be discussed under one heading in explaining their biological relations. Each disease has its own marked symptoms and recognizable germ, but so far as their biology is concerned all are similar. The bacteria gain access to our bodies and live parasitically, during which time the disease develops. The bacteria grow and multiply and carry on their own metabolism. *The result of this normal activity on their part is the production of poisons which disturb the cells of the human body; just which cells are interfered with depends upon the invading organism.* Each disease passes through several stages or cycles. The first of these stages is termed the incubation period and is the time that elapses between the entrance of the infection into the body and the day when the earliest symptoms appear. This idea of a period of incubation is well illustrated in the following table:

DISEASE WITH SHORT INCUBATION.

	Limits.	Usual time.
Diphtheria	2 to 7 days	2 days
Scarlet fever	1 to 8 days	3 to 4 days
Influenza	1 to 4 days	2 days
Erysipelas	3 to 7 days	4 to 5 days

DISEASE WITH LONG INCUBATION.

	Limits.	Usual periods.
Typhus fever	7 to 14 days	12 days
Typhoid fever	7 to 21 days	about 14 days
Chicken-pox	10 to 15 days	about 14 days
Smallpox	9 to 15 days	generally 11 or 12 days
Measles	7 to 18 days	generally 14 days
German measles	12 to 21 days	about 14 days
Mumps	14 to 21 days	about 16 days
Whooping-cough	7 to 14 days	about 10 days

The next stage is sometimes called the termination period, and there are various ways in which the disease comes to a close. The steady course may end abruptly, as in typhoid fever, and convalescence set in at once, or the decline may be very gradual, and it is

difficult to say just when it stops. The last stage comprises the changes occurring in the return to ordinary health and is termed convalescence. Each bacterial organism living in this parasitic relation shows certain peculiarities, as does the host, so that the conditions in any two cases are never exactly the same. The changes which the bacteria cause in the cells and tissues are likewise varied, so that general statements must be made; in one case ulcers appear, in another abscesses are formed or certain glands are swollen, etc. In the study of the bacterial diseases great care has been exercised to definitely isolate the specific germ that is the cause of the disease and work out its life-history and habits, as a result one can learn how to avoid infection by such germs. The number of persons dying annually from the bacterial diseases is very large, as one soon realizes from a study of the reports from any State board of health, but he also gains from such study the further important fact that all of these diseases are preventable. Whether the sanitary conditions of civilized nations will ever become so perfect as to prevent any considerable number of the bacterial diseases is a question, but it is the purpose of those who understand the wastefulness that comes from sickness and death due to these diseases to try greatly to reduce their number. The greatest work for medicine in the future is to be the prevention of disease instead of its cure.

New Diseases.—In 1922 the Bureau of Fisheries announced a new bacterial disease in fresh-water fishes and the same year the New York State Department of Health called attention to the occurrence during the autumn and winter of a number of outbreaks in different parts of the state of an unfamiliar disease, epidemic jaundice, evidently communicable in character. The cause of this disease and its exact nature have not been satisfactorily determined. The bacterium found in the fish was a species new to science and now that its habits are worked out and preventive measures have been discovered, fish can be protected from this disease. From time to time in the future we shall expect to learn that other organisms have taken on the parasitic habit either accidentally or as a result of the competition to gain a living and other maladies new to science will be reported. Until we come thoroughly to understand the adaptations which these new relations compel, remedial and protective measures cannot be adopted.

Parasitism and Immunity.—The significance of the acquired habit of parasitism in its larger relation to the subject of immunity is clearly brought out in the study of Texas fever as described by Dr. D. E. Salmon.

"The cattle which spread the disease are, themselves, apparently in good health, while the cattle that become sick do not themselves disseminate the contagion. Again, susceptible cattle might be mingled with impunity with cattle from the infected district, providing this mingling occurred immediately after their arrival, and did not continue longer than two or three weeks; while, on the other hand, susceptible cattle that later in the season trespassed for even a few minutes on the pastures where the infectious cattle had been would contract a most violent form of the malady . . Texas fever is caused by a microscopic parasite, which lives within the red globules of the blood. The cattle in the infected district carry this parasite permanently, and are so nearly immune to its effects that they remain in good health, notwithstanding its presence in their blood. Not so, however, with cattle which never before have encountered it. With such animals it destroys the red corpuscles and reduces them to one-third or one-fourth the normal number. An intense fever is produced, and the creatures rapidly waste away and die after a sickness of one or two weeks."

The East Coast fever of Africa, which is very similar, is caused by a closely related parasite which likewise lives in the red corpuscles of its host. Infected East Coast cattle show no ill-effects, but are "carriers" of the disease. Non-immune cattle brought into the East Coast region are open to certain attack, and the assertion has been made that out of each 100 which are thus assailed but 5 on the average survive. In one epidemic, due to the introduction of infected animals into the Transvaal, 15,000 cattle died. In trypanosomiasis (sleeping sickness) we have another instance of this same condition. Notwithstanding the fact that there may be no sick animals in the fly-country of Africa, no horses, cattle or dogs can venture, even for a day, into the region. Most of the wild animals, however, the buffalo, koodoo, and wildebeeste or gnu, carry the trypanosomes in small numbers in their blood, and it is from them that the tsetse fly obtains the parasite. The wild animals act as a reservoir of the disease. The trypanosome seems to live in the blood of the wild animals without doing them any manifest harm, but when introduced into the blood of such domestic animals as the horse, the dog, or the ox, the victims rapidly sicken and die.

Disease Carriers.—The part played by biology in helping to solve the nature of disease and of the various organisms that infect the body has been great, but biologists found an equally fertile field for study in unravelling the manner in which disease was carried from

the sick to the well. The recognition that definite living organisms are responsible for the transmission of disease has revolutionized the methods employed in fighting the further spread of many of the infectious diseases. *The term carrier is given to animals or persons who, apparently in good health, harbor and spread disease germs.* The fact that a man appears well and yet may be spreading disease is a new idea in preventive medicine. This in no way eliminates the old idea that contact with the sick furnishes a means of transmission of disease but rather adds another source of infection. During the convalescence of a patient it is to be expected that some germs will be found, but their persistence in a person after he is

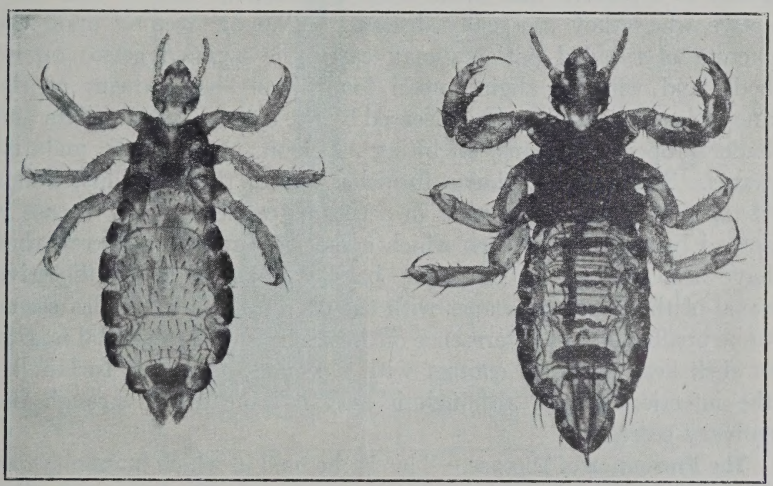


FIG. 243.—Male and female cooties, carriers of trench fever. Photograph furnished by U. S. Bureau of Entomology.

well or their existence in a person who has never had the disease is difficult to explain. Among men there are (1) convalescent, (2) chronic and (3) healthy carriers. Diphtheria and typhoid fever are two common diseases in connection with which carriers are found. The spread of epidemics is now frequently traced to a person who believed himself to be perfectly free from such germs. The elimination of the sporadic cases of diphtheria in certain schools is now readily accomplished by simply locating the diphtheria carriers in the school. Malta fever furnishes an interesting illustration of the principles involved. This disease is due to *Micrococcus melitensis*. The goat is really a chronic carrier of these bacteria. When the goats on the

island of Malta were examined by the British Commission fully 50 per cent. gave a test which showed that they were harboring the germs and 10 per cent. were actually secreting the bacteria in their milk. All that was necessary was to boil the goats' milk or avoid using it to put a stop to Malta fever. In a similar way milk tuberculosis is caused.

The part played by animals in acting as carriers for the protozoan diseases is of great importance, for they may act as the natural reservoirs of the virus and are thus responsible for the continued existence of the disease. Among the animals that act as carriers of the protozoa the insects rank first. Their relation to the animal germs is a passive one when they accidentally convey them and active when they are really diseased. The fly[1] feeding upon the excreta of typhoid patients may carry the typhoid germs on its body and when it alights upon food simply leave them; or the anopheles mosquito may be diseased by the malarial plasmodium and under proper conditions, on biting a person, transmit the malarial germs. The bubonic plague furnishes one of the best illustrations of the part played by insects in acting as carriers. This disease is spread by the bite of fleas which come from rats or squirrels that have been infected. The plague bacillus develops in the digestive canal of the flea and escapes with the excreta. While the flea seems to be unaffected by the presence of these germs, if the excretal matter of such fleas comes in contact with a wound, according to Hindle, the infection occurs, although it may be contracted through the salivary secretion.

The Prevention of Disease.—This is the field in which humanity can do its greatest work. The task is stupendous. The mere facts that certain diseases, like hook-worm, extend in a belt around the world and among the lowest forms of civilization, that tuberculosis is killing thousands annually, that malaria and yellow fever have devastated cities, and bubonic plague unrestricted may sweep through a nation, reveal something of the scope of the problem of prevention. *All diseases which are due to the presence of some organism are preventable, and this fact alone is one to furnish all with enthusiasm for a work that must continue for many years to come.* An important incident in the United States which indicates that there is a responsibility in the matter of preventing disease is the recent decision of one of the courts in Minnesota that a city is responsible

[1] The House-fly, Musca Domestica Linn: Its Structure, Habits, Development, Relation to Disease and Control. By C. Gordon Hewitt, Cambridge University Press.

for the purity of its water supply, and that when a person contracts typhoid fever and dies his heirs can sue the city for damages. Such a decision is an indication of progress. The world-wide dissemination of the truth about disease is an undertaking which will require years, but which must be accomplished in order to prevent the spread of plague from nation to nation.

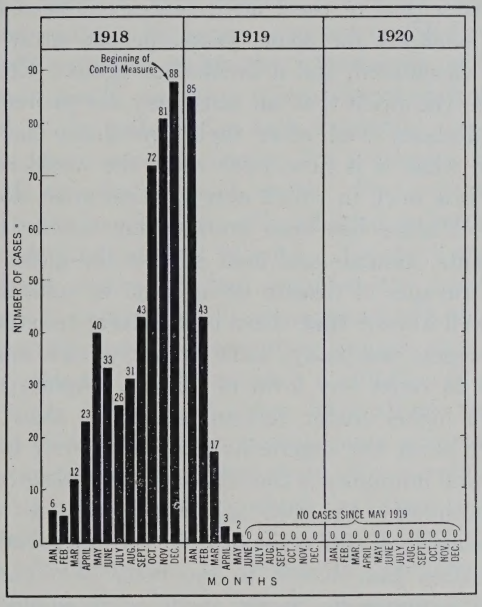


FIG. 244.—Chart showing sharp decline of yellow fever cases in Guayaquil, Ecuador, since the beginning of control measures, November, 25, 1918.

Scientists are able to approach the problem of prevention in an intelligent manner because of the recent discoveries in regard to carriers.

The first step in the progress of prevention is to destroy the insect carriers when practicable or to destroy or prevent their eating in order that they may not be able to reproduce.

Human beings who act as carriers must be isolated until free from the germs or be prevented from working at trades such as dairying and cooking, which enable them to spread the germs. It is sometimes necessary to quarantine chronic carriers. The insect carriers, with proper care, can be prevented from biting human beings, as is

illustrated by the conditions in the Panama Canal Zone, which used to be like Havana a pest-hole of disease. After a time the insect carriers should become free from disease germs if the germs are not allowed to gain access to them. When civilization has developed to the stage that all realize that disease from parasitism is wholly preventable, and that every epidemic is the result of carelessness, then we may expect that sanitary precautions will be observed. After the greater part of the United States has been free from any epidemic of smallpox for some years, people grow careless and neglect to be vaccinated, and it breaks out again. Eternal vigilance is going to be the price that all must pay for protection from the preventable diseases even after their prevalence has been greatly reduced from what it is now, even after the world recognizes that the problem is a work in which every nation must do its part.

Immunity.—Disease has been known from remote times and yet numerous plants, animals and men inhabit the globe. These have survived the ravages of disease or have never succumbed to infection. It is well known that there is a natural resistance to disease which men possess unequally; some are never sick and others seem to be unable to resist any form of disease. Again, our powers of resistance are higher under certain conditions than under others. This power to resist the organisms that invade our bodies is immunity, and natural immunity is the degree of immunity that each person possesses. Immunity has two aspects—resistance to the microorganisms themselves and resistance to the microbial poisons.

When microbes gain access to the body of a paramecium, for example, the paramecium treats them as it would any ingested particle of food, and if the protecting cell walls of the germs cannot be broken down the germs are eliminated. If the microbial toxins are brought in contact with these and other ciliate protozoans there is no appreciable effect upon the protozoa. They are able to tolerate the poisons. It has been known for some time that these simple animals are able to adapt themselves not only to altered physical conditions but to endure the toxic action of true poisons. Many of the common fresh-water fishes have injurious bacteria growing on their bodies just as man has pneumonia germs in his respiratory passages. These germs do no appreciable harm as long as the fish are healthy and vigorous but as soon as their resistance is lowered, the bacteria increase rapidly and many fish die. Resistance to the poisons of parasitic germs depends on keeping the body of fish fit just as it does in man. In studying the fundamental properties of

living matter this adaptability of living protoplasm must be ranked as one of the most important.

The problem of immunity is further illustrated by the degree of tolerance which different animals have to the same poisons. It is well known that sheep are the most susceptible of the mammals to the toxin of tubercle bacilli, while the guinea-pig is not very susceptible; but the guinea-pig is very susceptible to the tubercle bacilli and the sheep is very resistant, *therefore immunity to the poisons and immunity to the germs represent two distinct conditions.* The snail (*Helix pomatia*) resists the introduction of large quantities of anthrax bacilli and they soon disappear from the blood and are found in the cells of the foot, especially those which surround the pulmonary vessels. During this taking up of the anthrax bacilli the snail remains in good health. Forty-eight hours after the injection of the bacilli these cells afforded cultures which were capable of giving fatal anthrax to mice. Ten days or more passed before the phagocytes which had engulfed the bacilli had fully digested them. If anthrax bacilli are injected into the body of the perch, numerous leukocytes accumulate around and ingest them, although the peritoneal fluid furnishes a suitable culture medium for these bacteria. These and other illustrations that might be added serve to show that many animals have a natural immunity not only to the microbial poisons but also to the microbes themselves.[1]

Given this natural immunity, which is found to be generally distributed among all forms of life, how does it happen that there is any sickness? It is not easy to answer this question in a word or in an elementary course, but it may be suggested that *a sufficient number of germs within the body is necessary and that these germs must be virulent and the host receptive.* We are unable to state just what the conditions are that make a host receptive to germs or how to eliminate the condition. We say that the non-resistant host is susceptible, the resistant immune. When the germs have gained entrance to a susceptible host, does the disease begin as a result of their parasitic habit or are there other factors? The parasitic nature of disease was the early conception, but it was soon found that there were a number of conditions that mere parasitism did not explain. The disease frequently followed a course that suggested that it was similar to the fermentative action of yeast, etc., and so there arose the zymotic theory of germ disease. Later it was

[1] For the detailed study of immunity, the student is referred to Metchnikoff: Immunity in Infectious Diseases. Ehrlich: Studies on Immunity.

found that the natural living processes of the bacteria produced certain waste substances, by-products of growth which were of a poisonous character, and that some of the phases of a given disease could be induced by injecting the poison. There was thus added the toxic factor of disease. This is a most important phase of the cause of the bacterial diseases, as some of the disease bacteria show very little growth in the human body. Many writers hold that these two processes should be united and that the cause of the disease is "zymotoxic." The details of this theory as well as the details connected with recovery from disease are taken up in advanced courses. It must suffice here to mention in brief outline some of the main points.

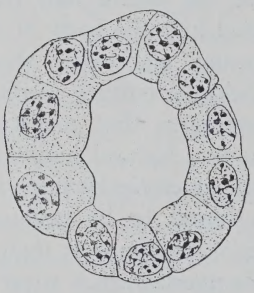


FIG. 245

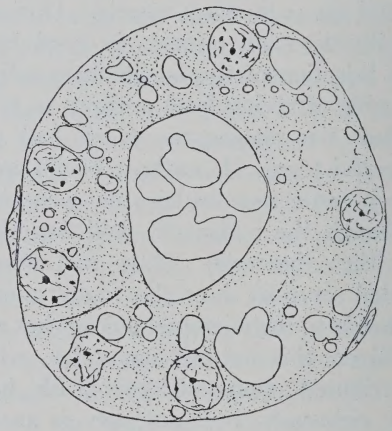


FIG. 246

FIG. 245.—Kidney cells of normal frog. Compare these cells with those in Fig. 246.

FIG. 246.—Cross-section of kidney tubule of hemorrhagic frog. The bodies with a continuous outline in the lumen and in the cytoplasm are the degenerating red blood corpuscles. This is an illustration of adaptation in the cells of the kidney to meet an emergency—the hemorrhage. (Kidney Cells of the Frog in a Phagocytic Role, Anat. Anz., 1908, Bd. xxxii, No. 8.) How do the nuclei in these cells differ from those in Fig. 245?

The disease germs are destroyed by the phagocytes which ingest them and this process is fundamentally a feeding process just as is the case in the protozoa, but they are also destroyed by the juices of the body. It is believed that the body is able to secrete certain substances (antitoxins) which have the property of neutralizing the toxic products of the bacteria and this gives the cells of the body a chance to recover. As a result of having had certain dis-

eases one is said usually to be protected from a second attack. This is the case with most of the childhood diseases, such as measles, whooping-cough, etc. When the cells of the body have become thus protected against a second attack the term *acquired immunity* is used to distinguish it from the natural immunity which was not sufficient in such cases to prevent the disease. Acquired immunity is not a permanent condition of the cells and may disappear after one, two, three or more years.

FIG. 247.—Photograph of a spruce tree which has tipped over, due to the action of the waves on the roots. The tip of the tree has adapted itself to this new position, while two of the branches have become tree-like in their symmetry and bear cones. This adaptation is especially interesting, because it shows how the tree underwent a radical modification in attempting to adjust itself to its new position. The tree-like symmetry of the two limbs is a conspicuous illustration of this change.

Protection and Adaptation.—Since Jenner, in 1798, attempted to imitate nature and produce an immunity to certain diseases, men have been anxious to find a means of protecting their bodies from the ravages of disease. There are now some dozen or more diseases which have their antitoxin, vaccine, etc. If it were possible to remove the germs which cause disease all of these would be unnecessary. The underlying principle in the use of these protective agents (and there must be a specific one for each disease because the toxin produced by each different germ is distinct) is gradually to accustom the cells of the body to the poison in a mild form, so that during

the process they will elaborate antibodies to the particular poison produced by the given organism. It is significant to note in this connection that an antibody appears in the blood whenever protein is artificially introduced into the blood. When proteins are thus injected into the blood they act as a poison, which furnishes an artificial condition that closely approximates the toxin condition arising from bacteria. There has recently been discovered a new species of antelope in East Africa, the rock-loving, klippspringer.

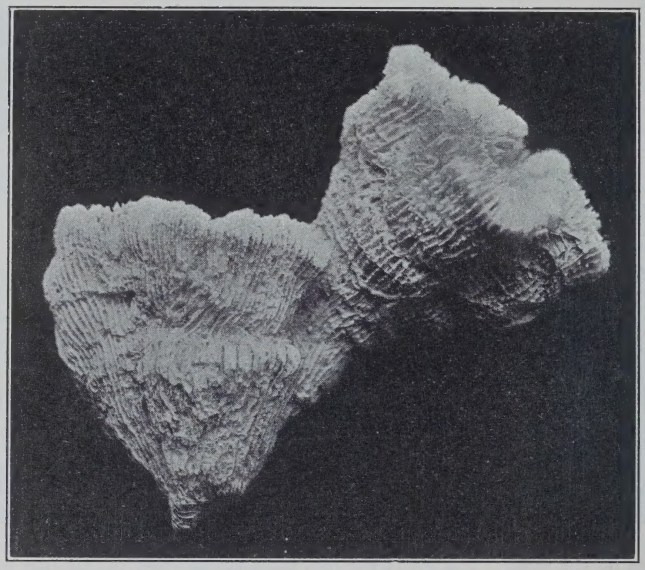


FIG. 248.—Photograph of cup coral taken at Bermuda. A heavy wind storm nearly buried in the mud the coral at the bottom and left of the figure, leaving one corner uncovered. The animal free from the mud grew up at the angle shown in the figure. The coral in adapting itself to the extremes of its environment grew in this asymmetrical manner. This figure, like Fig. 247, gives one some idea of the extent and possibilities of adaptation in nature.

This species is bush-feeding and regularly eats the leaves of a bush that belongs to the genus *Strychnos*. This is the plant from which the deadly drug strychnin is obtained, which, indeed, is a strange adaptation. The principle thus employed is as old as the study of biology and is everywhere apparent in nature. This adaptation is one in which the living protoplasm of certain cells plays the important part. Tuberculosis may occur in the lungs; diphtheria has its location in the throat or nose; while typhoid fever is found in the

blood and may be localized in the intestines, and it may be assumed that the cells which acquire an immunity to each of these diseases are not the same. In vaccination against smallpox the germs of cowpox, a mild form of smallpox, are introduced into the body, and through the reactions of the cells of the body to the cowpox virus the subject acquires a greater power to withstand the virulent smallpox virus. This acquired toleration lasts through a variable number of years, but usually not more than seven. Intelligent people always keep themselves immune to smallpox, because no one can tell when or how he will be exposed. Before the days of vaccination at least one-third of all persons took smallpox and this disease was the cause of about one-third of all deaths. All modern nations are immunizing their armies against typhoid fever, and the result has been almost entirely to prevent typhoid fever among our soldiers. Men and women in civil life should become immunized against typhoid fever unless they are confident that their water supply and milk are clean. The shop, the factory, the dairy, the mine, the canning industry, the meat-packing concerns, hotels, etc., all have or must adopt a new regimen as a result of the discoveries in biology in recent years. The application of these discoveries through municipal, state and national agencies is made possible only as these biological problems are analyzed by the scientific method. This form of analysis clearly indicates that all of these parasitic relations are acquired adaptations and best understood and explained by evolution.

Prolongation of Life.—The average length of life in the United States is fifty-six years which is a gain of three and a half years in expectation since 1910. Life has been lengthened for the average person fifteen years since 1870. This has been brought about by first discovering the exact causes of the diseases and second by applying scientific methods in eliminating these causes. While there are a number of diseases that exact a large toll of human life annually, enough is already understood about the common germ diseases and their origin that if we were able to apply the recognized remedial measures approved by the united concensus of scientifically trained men, it would be possible to add twenty years to the expectation of human life in the next fifty years.

President Vincent of the Rockefeller Foundation in 1921 writes: "The presence of smallpox is now a disgrace to any civilized community or country; cholera and the plague have disappeared from the leading nations; typhoid fever has been enormously reduced; malaria and hook-worm disease are giving ground; yellow fever is being narrowly

restricted; typhus is practically unknown among a cleanly people; the fear of diphtheria has been largely allayed. Such victories as these, together with advances in general sanitation, higher living standards, more attention to individual health habits, have resulted in steadily falling death rates in all the more progressive countries."

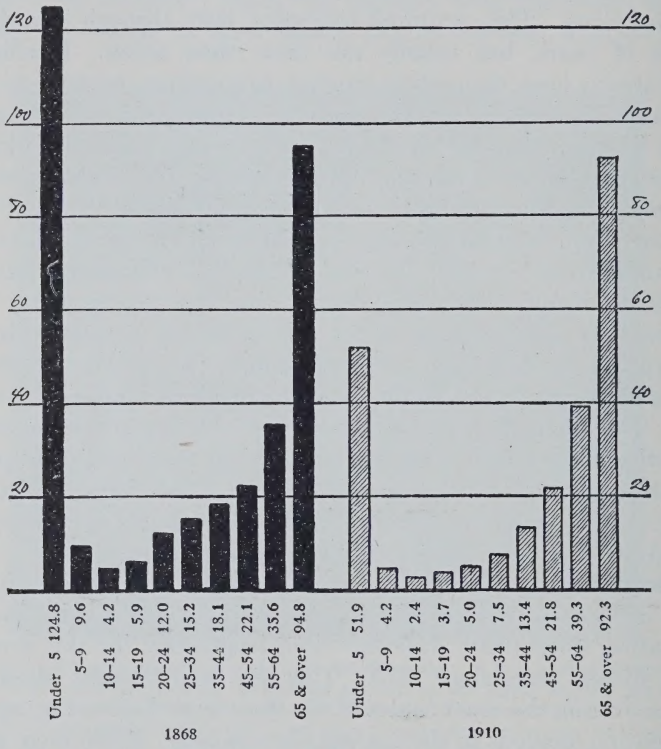


FIG. 249.—Death rates at different ages in 1868 and in 1910 in Manhattan and Bronx. (Monthly Bulletin of the New York City Department of Health, January, 1911.)

Nearly every time that the human mind comprehends another of the mysteries of protoplasm civilization marches forward. It is only when we come to grasp the enormous significance of such studies in adaptation that one realizes the part played by biological science in human betterment. But the battle is not won for we are in ignorance about how to prevent cancer and heart disease still claims more lives than any other. Another unsolved problem is the difference in the death-rate between males and females, a fact which has been recognized for some years so that an old chart serves as well as any other.

(Fig. 249.) A study of still-births shows the same difference; nor is this due to environment for a comparison of the death rate in the poor and well-to-do districts of a city give the same results. Here is then a field for investigation. A recent study of the death-rate in animals gives a higher percentage for males than females which suggests that the whole question may be one of general application and be based on some fundamental difference growing out of the sex glands and their influence on the whole body. In all studies of the death-rate there is the high percentage of deaths below five years of age, then a sudden drop with the lowest between the ages of ten and fourteen. From this period the death-rate slowly rises until around the age of forty-five when there is a marked increase. In the numerous studies that have been made to reduce the death-rate, the causes of death in middle aged men in particular have been overlooked. The loss which thus comes at a time when one is just reaching his maximum efficiency will be overcome when people come to understand the causes which operate especially at this age. In general the deferring of death for such persons is a question of studying their general fitness to resist the parasitic germs which usually gain rapid headway whenever our natural defenses give way.

GENERAL SUMMARY

In the taxonomic discriptions of organisms a large degree of accuracy has been secured. The students of organic activities are becoming more expert in devising methods that give an exact record of these changes so that one has confidence in their results. The scientific method has enabled the workers in these two phases of biology to make discoveries about life that will stand the test of time.

Is this same method applicable to the more theoretical aspects of biology and does it give equally satisfactory results?

In the study of variation, mathematical methods were introduced some thirty years ago. Exact measurements were employed and the results expressed graphically, giving one of the finest examples of the scientific method because any one can retrace all of the steps.

Since the rediscovery of Mendel's work, exactness has become the watchword in the numerous experiments in this great field and the scientific method gives results in variation and heredity that are as reliable as those in taxonomy.

Man's attempt to reconstruct the life of the past from partial

skeletal remains has passed through the trial and error stage and is rapidly becoming an exact science; while the germ theory of disease employed the verification method from the time of Pasteur. *One finds the utmost integrity back of all the facts that constitute the present day science of* BIOLOGY.

In every attempt at an explanation of these biological facts, one is limited by the characteristics common to all life. There are limits beyond which living protoplasm does not pass and one's conclusions must recognize these barriers. Even in the theoretical phases of biology which we have sketched under "The Significance of Fossils," "Geographical Distribution," and several phases of "Adaptation," the scientific method has been used and we trust that the conclusions are worthy of confidence.

We may appropriately summarize the significance of the scientific method by quoting from Prof. John Dewey: "One of the only two articles that remain in my creed of life is that the future of our civilization depends upon the widening spread and deepening hold of the scientific habit of mind; and that the problem of problems in our education is therefore to discover how to mature and make effective this scientific habit. Mankind, so far, has been ruled by things and by words, not by thought, for until the last few annals of history humanity has not been in possession of the conditions of secure and effective thinking. Without ignoring in the least the consolation that has come to men from their literary education I would even go so far as to say that only a gradual replacing of the literary by the scientific education can assure to man the progressive amelioration of his lot. Unless we master things, we shall continue to be mastered by them."

APPENDIX.

CLASSIFICATION OF ANIMALS AND PLANTS.

Animal Kingdom.—The following general plan of classifying the animal kingdom is taken from Parker and Haswell, and serves to show how animals are grouped, but does not determine the exact relation of even the great phyla.

I. Phylum Protozoa, 8500 species living.
  Classes 1. Rhizopoda: amœba.
  2. Mycetozoa.
  3. Mastigophora: spirochetes, trypanosomes.
  4. Sporozoa: gregarines, all parasitic.
  5. Infusoria:
    Class Ciliata.
    Order, Holotrichida.
    Family, Paramedicæ.
    Genera, Paramecium.
    Species: Paramecium caudatum, Paramecium aurelia.

II. Phylum Porifera, 2500 species.
  Class Porifera; sponges.

III. Phylum Cœlenterata: 4500 species.
  Classes 1. Hydrozoa: hydra, sea-anemone, jelly-fish.
    Hydrariæ.
    Hydra viridis.
    Hydra fusca.
  2. Scyphozoa: jelly-fish.
  3. Actinozoa: corals.
  4. Ctenophora.

IV. Phylum Platyhelminthes: 5000 species.
  Classes 1. Turbellaria: flatworms.
  2. Trematoda: liver fluke.
  3. Cestoda: tape-worms.

V. Phylum Nemathelminthes, 1500 species.
Classes 1. Nematoda: ascaria, trichina, uncinaria.
2. Acanthocephala: hook-headed worms, echinorhynchus.
3. Chetognatha.

VI. Phylum Trochelminthes, 500 species.
Classes 1. Rotifera.
2. Dinophilea.
3. Gastrotricha.

VII. Phylum Molluscoida, 1837 species.
Classes 1. Polyzoa.
2. Phoronida.
3. Brachiopoda.

VIII. Phylum Echinodermata, 4000 species.
Classes 1. Asteroidea: star-fish.
2. Ophiuroidea: brittle stars.
3. Echinoidea: sea-urchins.
4. Holothuroidea: sea-cucumbers.
5. Crinoidea: crinoids.

IX. Phylum Annulata, 4000 species.
Classes 1. Chetopoda: earthworms.
Oligocherta.
Lumbricidæ.
Lumbricus terrestris: Common earthworm.
2. Gephyrea.
3. Hirudinea: leeches.

X. Phylum Arthropoda, 507,000[1] species.
Classes 1. Crustacea, 16,000 species: Crabs, lobsters, etc.
Macrura.
Astacidæ.
Astacus Cambarus: Common crayfish.
2. Onychophora.
3. Myriapoda, 1000 species: centipedes.
4. Insects, 470,000 species.
1. Order Aptera: spring-tails, snow-fleas.
2. Order Ephemeridæ: May-flies.
3. Order Odonata: dragon-flies, damsel-flies.
4. Order Plecoptera: stone-flies.
5. Order Isoptera: white ants.
6. Order Corrodentia: book-lice, bark-lice.

[1] Some authorities estimate that the insects alone number 600,000.

7. Order Mallophaga: biting bird-lice.
8. Order Thysanoptera: thrips.
9. Order Euplexoptera: earwigs.
10. Order Orthoptera: cockroaches, grasshoppers.
11. Order Hemiptera: bugs, head-louse.
12. Order Neuroptera: ant-lion, dobson-fly.
13. Order Mecoptera: scorpion-flies.
14. Order Trichoptera: caddis-flies.
15. Order Lepidoptera: butterflies, moths.
16. Order Diptera: flies.
17. Order Siphonaptera: fleas.
18. Order Coleoptera: beetles, potato-bug.
19. Order Hymenoptera: bees, ants, wasps.
    Apidæ.
    Apis mellifica. Honey bee.

XI. Phylum Mollusca, 61,000 species.
Classes 1. Pelecypoda: clams, oysters.
Unionidæ.
Anontoides.
Anodonta fluviatiles.
2. Amphineura.
3. Gastropoda: snails.
4. Cephalopoda: squid, devil-fish.

XII. Phylum Chordata.
Subphylum 1. Adelochorda.
2. Urochorda: tunicate, 1300 species.
3. Vertebrata.
Acrania: amphioxus.
Craniate.
Classes 1. Cyclostomata: lamprey.
2. Pisces: fishes, 13,000 species.
3. Amphibia: 1400 species.
Urodela: salamanders.
Anura: frogs and toads.
Salienta.
Ranidæ.
Rana pipiens.
Rana catesbiana.
Rana clamitans.

4. Reptilia: horned toad, lizard, snake, turtle, alligator, 3500 species.
5. Aves: birds, 13,000 species.
6. Mammalia: dog, cat, sheep, seal, rabbit, monkey, man, etc., 3500 species.

The Plant Kingdom.—Largely from Bergen and Caldwell.

Phylum I. Thallophyta.
- Subphylum I. Myxomycetes: slime moulds, sometimes classed as animals.
- Subphylum II. Schizophyta. 2020 species.
  - Class I. Schizomycetes: bacteria.
  - Class II. Schizophyceæ: blue-green algæ.
- Subphylum III. Algæ.
  - Class I. Chlorophyceæ: the green algæ, 8950 species.
  - Class II. Pheophyceæ: the brown algæ, 1030 species.
  - Class III. Rhodophyceæ: the red algæ, 3050 species.
- Subphylum IV. Fungi. 64,400 species.
  - Class I. Phycomycetes: moulds and mildews.
  - Class II. Ascomycetes: mildews, cup-fungi, etc.
  - Class III. Lichens.
  - Class IV. Basidiomycetes: mushrooms, rusts, etc.

Phylum II. Bryophyta.
- Class I. Hepaticæ: liverworts, 4000 species.
- Class II. Musci: mosses, 12,600 species.

Phylum III. Pteridophyta.
- Class I. Filicineæ: true ferns, 3800 species.
- Class II. Equisetinæ: scouring rushes or horse-tails, 24 species.
- Class III. Lycopodineæ: club mosses or ground pines, 700 species.

Phylum IV. Spermatophyta.
- Subphylum I. Gymnosperms, 540 species.
  - Order. Coniferales: pine, spruce, firs, etc.
- Subphylum II. Angiosperms.
  - Order I. Monocotyledons: corn, grasses, lilies, etc., 23,700 species.
  - Order II. Dicotyledons: hardwood trees, roses, etc., 108,800 species.

GLOSSARY.

A

Abiogen'esis (Gr. *a*, not + *bios*, life + *genesis*, birth). The origin of living things from non-living matter, a theory that is no longer accepted. The same as *spontaneous generation*.

Achro'matine (Gr. *a*, not + *chroma*, color). That portion of the nucleus that does not take a stain, also applied to that portion of the mitotic figure that does not stain deeply.

Acra'nia (Gr. *a*, not + *kranion*, skull). The lowest group of vertebrata, the group without a skull.

Ac'tivator (L. *agere*, to act). A substance which renders some other substance active.

Adduc'tor (L. *ad*, to + *ducere*, bring to). The large muscle in clams that closes the valves; the name of any muscle that pulls the parts toward the median line.

Ad'ipose (L. *adeps*, fat). The name for fat tissue.

Adre'nal (L. *ad*, to + *renes*, kidney). A gland situated on or above the kidney. The same as suprarenal. The internal secretion, known as *adrenalin* is produced in this gland.

Af'ferent (L. *ad*, to + *ferre*, to carry). The nerve fiber that carries stimuli to the central nervous system.

Al'binism (L. *albus*, white). The whole or partial absence of the normal pigmentation in the hair, feathers or skin.

Alve'olar (L. *alveolus*, a small hollow). Used especially to describe the structure of cytoplasm when it is foam-like.

Amino-acid (derivation uncertain). One of the stages in the digestion of proteins.

Am'phiaster (Gr. *amphi*, double + *aster*, star). The complete mitotic figure consisting of spindle and two asters.

Amphib'ia (Gr. *amphi*, double + *bios*, life). A class of vertebrates adapted to living both on land and in the water.

Amphiox'us (Gr. *amphi*, double + *oxys*, sharp). The simplest group of the vertebrates, also known as *acrania*.

Amylop'sin (Gr. *amylon*, fine meal + *opsis*, appearance). The enzyme secreted by the pancreas that digests starch.

Anab'olism (Gr. *ana*, up + *ballein*, to throw). The up-building or constructive phase of metabolism.

An'aphase (Gr. *ana*, up + *phasis*, appearance). A stage in mitosis during which the divided chromosomes move from the equatorial plate of the spindle toward the poles of the same.

Anten'na (L. *antenna*, a sail-yard). A jointed sensory organ on the head of insects and crabs.

Ante'rior (L. *anterior*, comp. of ante, before). Toward the front.

Antheri'dium (Gr. *antheros*, flowery + *idion*, diminutive ending). The spore-bearing organ in lower plants.

An'thrax (Gr. *anthrax*, carbuncle). A malignant pustule, characteristic of the disease anthrax.

Antitox'ine (Gr. *anti*, against + L. *toxicum*, a poison). A substance in the blood after certain diseases conferring immunity from further attacks for a longer or shorter period.

Anu'ra (L. *an*, not + Gr. *oura*, tail). An order of amphibia without a tail in the adult stage.

A'nus (L. *anus*, ring). The posterior opening of the alimentary tract.

Aor'ta (Gr. *aeirein*, to lift). The main trunk of the arterial system.

Apo'da (Gr. *a*, not + *pous*, foot). Any of several groups of animals that have been so named from their lacking limbs or feet.

Archen'teron (Gr. *archi-*, beginning + *enteron*, intestine). The primitive digestive sac of an embryo.

Arthrobran'chia (Gr. *arthron*, joint + *bragchion*, gill). A gill attached to the articular membrane between the body and basal joint of a crustacean.

Arthrop'oda (Gr. *arthron*, joint + *pous*, foot). A group of invertebrates with jointed feet, such as crabs and insects.

Asex'ual (L. *a*, not + *sexus*, sex). Organisms that reproduce without germ cells.

Au'ricle (L. *auricula*, little ear). The upper chambers of a vertebrate heart.

Au'totrophic (Gr. *autos*, self + *trophikos*, nursing). Capable of self nourishment.

Ax'on (Gr. *axon*, axis). An outgrowth from the nerve cell that usually carries stimuli away from the body of the cell.

B

Biogen'esis (Gr. *bios*, life + *genesis*, birth). The origin of living things from preëxistent life. One of the most important of modern generalizations concerning living matter.

Biol'ogy (Gr. *bios*, life + *logos*, discourse). The science of living things.

Blas'tocœle (Gr. *blastos*, sprout + *koilos*, hollow). The segmentation cavity.

Blas'topore (Gr. *blastos*, sprout + *poros*, passage). The opening through which the archenteron communicates with the exterior. (See Archenteron.)

Blas'tula (diminutive of Gr. *blastos*, sprout). An early stage in development consisting of a hollow sphere of cells.

Brachiop'oda (Gr. *brachion*, arm + *pous*, foot). A group of nearly extinct molluscoidea

Brach'ydont (Gr. *brachys*, short + *odous*, tooth). Short crowned teeth with well-developed roots.

Bryoph'yta (Gr. *bryon*, moss + *phyton*, plant). The phylum of plants containing the mosses and liver-worts.

C

Calcif'erous (L. *calx*, lime + *ferre*, to bear). Glands which produce calcium or lime. Found in the earthworm.

Car'diac (Gr. *cardia*, heart). Pertaining to or situated near the heart.

Cat'alyzer (Gr. *kata*, wholly + *lyein*, to loose). An agent which decomposes without itself undergoing change.

Cen'trosome (Gr. *kentron*, center + *soma*, body). The body at the center of the aster in the amphiaster.

Cephalotho'rax (Gr. *kephale*, head + *thorax*, thorax). The united head and thorax in crustaceans.

Chias'ma (Gr. *chiasma*, a cross). The intersection of the optic nerves on the floor of the brain of vertebrates.

Chi'tin (Gr. *chiton*, a gown or tunic). A white, horny substance forming the harder part of the integument of some invertebrates.

Chlor'ogogue (Gr. *chloros*, light green + *agogos*, leading). A layer of glandular cells covering the outer surface of intestine of earthworm.

Chlo'rophyll (Gr. *chloros*, light green + *phyllon*, leaf). The green coloring matter in plants.

Chlo'roplast (Gr. *chloros*, light green + *plastos*, formed). A minute granule saturated with green pigment.

Chorda'ta (Gr. *chorde*, cord). The phylum of animals that at some stage have a more or less well-developed notochord.

Chro'matine (Gr. *chroma*, color). That portion of the nucleus that takes a deep stain and forms the chromosomes.

Chro'momere (Gr. *chroma*, color + *meros*, part). One of several minute parts in the chromosome.

Chro'mosome (Gr. *chroma*, color + *soma*, body). A deeply staining body in the nucleus which becomes a part of the chromatine net-work.

Chromo'lysis (Gr. *chroma*, color + *lyein*, to loose). The solution and disintegration of cell and nuclei.

Cloa'ca (L. *cloaca*, sewer). The lower end of the digestive canal in fishes, amphibians, reptiles and birds.

Cni'docil (Gr. *knide*, nettle + L. *cilium*, eye-lash). A delicate sensory hair on a nematocyst.

Cœcil'ian (L. *cœcus*, blind). A class of blind amphibians.

Cœlentera'ta (Gr. *koilos*, hollow + *enteron*, intestine). A phylum of invertebrates with a digestive cavity, but lacking a cœlome.

Cœ'lome (Gr. *koiloma*, hollow). Body cavity containing digestive and excretory organs.

Cœ'nocyte (Gr. *koinos*, common + *kytos*, hollow vessel). An organism composed of a number of united protoplasts forming a single cell.

Cell'oid (Gr. *kolla*, glue + suffix *oidos*, form). A substance of a gelatinous nature, opposed to crystaline.

Co'lon (Gr. *kolon*, colon). The large intestine from cæcum to rectum.

Con'jugate (L. *con*, with + *jugare*, join). The temporary union of protozoön cells, during which there is an exchange of nuclear material.

Cor'puscle (L. diminutive of *corpus*, body). A free or embedded cell.

Cot'yledon (Gr. *kotyledon*, a socket). The seed leaves of a plant.

Crania'ta (Gr. *kranion*, skull). Vertebrates with a true skull.

Cryptogam'ia (Gr. *kryptos*, hidden + *gamos*, marriage). A sub-kingdom of plants not producing flowers or seeds.

Cu'ticle (L. diminutive of *cutis*, skin). A non-cellular membrane.

Cy'tose (Gr. *kytos*, hollow vessel + *stenai*, to stand). An enzyme rendering soluble plant cell walls.

Cy'toplasm (Gr. *kytos*, hollow vessel + *plasma*, a mold). The protoplasm of the cell exclusive of the nucleus.

D

Den'drite (Gr. *dendron*, a tree). A tree-like branching process of a nerve cell.

De'siccate (L. *de*, from + *siccare*, to dry). To dry up.

Dihy'brid (Gr. *dis*, twice + *hybrida*, a hybrid). The offspring of parents that differ in two characters.

Dimorph'ism (Gr. *dis*, twice + *morphe*, form). Differences between members of the same species. Also used to distinguish the different individuals in a hydroid colony.

Diploblas'tic (Gr. *diploos*, double + *blastos*, sprout). The two-layered condition of the body wall in cœlenterata.

Di'ploid (Gr. *diploos*, double + *eidos*, form). The complete tissue number of chromosomes and the number in germ cells previous to maturation. (See Haploid.)

Disac'charid (Gr *dis*, twice + L. *saccharon*, sugar). Any of a group of sugars that yield two monosaccharid molecules on hydration.

Dissep'iment (L. *dis*, separate + *sœpire*, to hedge in). A transverse partition.

Dom'inant (L. *dominus*, master). One of a pair of characters possessed by one parent, which appears in the offspring and excludes the same character from the other parent (the recessive). *Recessive* (L. *re*, back + *cedere*, to go). The character possessed by one of the parents which does not appear in the first hybrid generation but does later.

Dor'sal (L. *dorsum*, the back). The region of the body opposed to the ventral.

E

Ecol'ogy (Gr. *oikos*, home + *logos*, discussion). That branch of biology which treats of the mutual relations between organisms and their environment.

Ec'toderm (Gr. *ektos*, outside + *derma*, skin). The outer investing cellular membrane of multicellular animals.

Ec'toplasm (Gr. *ektos*, outside + *plasma*, thing formed). The external layer of protoplasm in a cell. Same as ectosarc.

Effec'tor (L. *ex*, out + *facere*, to make). Muscle and gland cells that react to stimuli.

Ef'ferent (L. *ex*, out + *ferre*, to bear). Nerve fibers that carry stimuli away from the central nervous system.

Encyst'ment (Gr. *en*, in + *kystis*, sac). The formation of an impermeable envelope, especially in unicellular organisms.

En'docrine (Gr. *endo*, within + *crinis*, hair). The name of the internal secretions, same as ductless.

En'doderm (Gr. *endo*, within + *derma*, skin). The layer of cells lining the archenteron.

En'doplasm (Gr. *endo*, within + *plasma*, thing formed). The inner or central portion of the cytoplasm in a cell. The same as endosarc.

Endop'odite (Gr. *endo*, within + *pous*, foot). The internal or mesial branch of a typical limb of a crustacean.

En'zyme (Gr. *en*, in + *zyme*, leaven). A soluble ferment, a catalytic agent.

Esoph'agus (Gr. *oiso*, will bear + *phagein*, to eat). The tube that leads from the pharynx to the stomach.

Eusta'chian (Eustachi, a learned Italian physician, died 1574). A channel of communication between middle ear and pharynx.

Exop'odite (Gr. *ex*, out + *pous*, foot). The external branch of a typical limb of a crustacean.

Ex'siccate (L. *ex*, out + *siccare*, to dry). To artificially exhaust moisture from animals.

F

Fe'ces (L. *faex*, dregs). The indigestible residue of the digestive tract.

Fibrin'ogen (L. *fibra*, fiber + Gr. *genes*, akin to). A soluble protein in the blood.

Fibrovas'cular (L. *fibra*, fiber + *vasculum*, small vessel). The conductive system of plants.

Fis'sion (L. *findere*, to split). The division of an organism into two equal parts, especially in protozoa.

Flagel'lum (L. *flagellum*, whip). A long whip-like process of a cell, a specialized cilium.

Fun'gus (L. *fungus*, mushroom). A plant which lacks chlorophyll.

G

Gam'ete (Gr. *gamein*, to marry). A conjugating cell which unites with another of like or unlike character to form a new individual.

Gan'glion (Gr. *ganglion*, tumor). A collection of nerve cells.

Gas'trula (Gr. *gaster*, stomach). The two-layer stage in development.

Germ (L. *germen*, sprig). The cells considered collectively as distinguished from the body or soma cells.

Gin'glymoid (Gr. *gigglymos*, hinge-joint + *eidos*, form). Pertaining to a hinge-joint.

Glob'ulin (L. diminutive of *globus*, globe). A group of proteins.

Glochid'ium (Gr. *glochis*, point of an arrow). The larva of fresh-water mussels.

Glomer'ulus (L. *glomere*, make a ball). Minute rounded bodies in the cortex of a kidney; a knot of bloodvessels; a Malphigian body.

Gon'ad (Gr. *gone*, that which generates). A reproductive gland.

Gon'ophore (Gr. *gone*, that which generates + *pherein*, to bear). A reproductive individual in a hydroid colony.

H

Hap'loid (Gr. *haploos*, simple + *eidos*, form). Having the reduced number of chromosomes in germ cells after maturation. (See Diploid.)

He'moglobin (Gr. *haima*, blood + L. *globus*, globe). The red coloring matter in blood.

Hemol'ysis, same as Haematolysis (Gr. *haima*, blood + *luein*, loosen). Dissolution of red blood corpuscles.

Hepat'ic (Gr. *hepar*, liver). Pertaining to the liver.

Hermaph'rodite (Gr. *Hermaphroditos*, from the Greek story about Hermaphroditos). An individual having both male and female reproductive organs.

Heterotroph'ic (Gr. *heteros*, other + *trophikos*, nursing). Deriving nourishment from without; opposed to autotrophic.

Homol'ogy (Gr. *homologia*, agreement). Correspondence in type of structure between different organisms.

Hor'mone (Gr. *hormaein*, to excite). Substances secreted directly into the blood, carried by circulation to excite action in a different part of the body; chemical messengers.

Hy'brid (L. *hybrida*, mongrel). The offspring of parents of two different species or varieties.

Hy'dranth (Gr. *hydor*, water + *anthos*, flower). The nutritive individual in a hydroid colony.

Hydrocaul'us (Gr. *hydor*, water + *kaulos*, stalk). The stem of a hydroid.

Hy'droid (Gr. *hydor*, water + *eidos*, like). A group of hydra-like animals.

Hydrorhiz'a (Gr. *hydor*, water + *riza*, root). The root-stock attaching hydroids to other objects.

Hymenop'tera (Gr. *hymen*, a membrane + *pteron*, wing). An order of insects, bees and wasps.

Hy'pha (Gr. *hyphai*, a web). The strands or threads which make up the body of a fungus.

Hyp'sodont (Gr. *hypsos*, heigh + *odous*, tooth). Teeth with high crowns and short roots; opposed to brachydont.

I

Ileocol'ic (L. *ileum*, flank + *kolon*, colon). Pertaining to the ileum and colon.

Immu'nity (L. *immunis*, free from duty). Resistance to the toxin of disease-causing organisms.

Infundib'ulum (L. *infundibulum*, funnel). A hollow process on the floor of the brain.

In'sulin (L. *insula*, island). The internal secretion from the special cells of the pancreas, a recently discovered treatment for diabetes.

Invertebra'ta (L. *in*, not + *vertere*, to turn). Animals which lack vertebra.

K

Katab'olism (Gr. *kata*, down + *ballein*, to throw). Destructive metabolism; opposed to anabolism.

L

Leu'cocyte (Gr. *leykos*, white + *kytos*, hollow vessel). A white blood corpuscle.

Li'nin (L. *linum*, flax). The substance of the achromatic fibrous network of the nucleus.

Li'pase (Gr. *lipos*, fat). A fat enzyme.

Lip'ochrome (Gr. *lipos*, fat + *chroma*, color). A yellow pigment.

Lu'ciferase (L. *lux*, light + *ferre*, to bring + Gr. *stenai*, to stand). An enzyme acting on luciferin to produce light.

Lucif'erin (L. *lux*, light + *ferre*, to bring). Light-bearing.

Lu'men (L. *lumen*, opening). The space or opening in glands or other body cavities.

Lymph (L. *lympha*, clear water). A fluid resembling plasma which fills intercellular spaces.

M

Macronu'cleus (Gr. *makros*, large + L. *nucleus*, kernel). The larger of the two kinds of nuclei of many infusoria.

Maxil'liped (L. *maxilla*, jaw + *pes*, foot). An appendage near the mouth in crustacea.

Megagam'ete (Gr. *megas*, great + *gamein*, to marry). The larger of the two conjugating gametes; opposed to microgamete.

Meg'aspore (Gr. *megas*, great + *spora*, seed). One or two kinds of asexual spores in plants; opposed to microspore.

Mel'anism (Gr. *melas*, black). An unusual development of black or nearly black color; opposed to albinism.

Mes'entery (Gr. *mesos*, middle + *enteron*, intestine). A fold of tissue supporting the intestine.

Mes'oderm (Gr. *mesos*, middle, + *derma*, skin). The middle germ layer.

Mesoglœ'a (Gr. *mesos*, middle + *gloios*, glutinous substance). The middle non-cellular layer in cœlenterata.

Mesozo'ic (Gr. *mesos*, middle + *zoe*, life). A late period in geologic history.

Metab'olism (Gr. *meta*, with + *ballein*, to throw). The sum of the processes concerned in the building-up of protoplasm and its destruction; includes anabolism and katabolism.

Met'amere (Gr. *meta*, with + *meros*, a part). One of the similar segments composing the body of many animals.

Metamor'phism (Gr. *meta*, beyond + *morphe*, form). The term to describe life histories of animals that pass through several changes, like butterflies and frogs.

Met'aphase (Gr. *meta*, after + *phasis*, appearance). A stage in mitosis in which the chromosomes have been drawn to the equator of the spindle.

Microgam'ete (Gr. *mikros*, small + *gamein*, to marry). The smaller of the two conjugating gametes; opposed to megagamete.

Micronu'cleus (Gr. *mikros*, small + L. *nucleus*, kernel). The smaller of the two kinds of nuclei of many infusoria; opposed to macronucleus.

Mi'crospore (Gr. *mikros*, small + *spora*, seed). One of two kinds of asexual spores in plants; opposed to megaspore.

Mi'ocene (Gr. *meion*, less + *kainos*, new). One of the more recent geologic periods.

Mollus'ca (L. *mollis*, soft). A group of invertebrata.

Monohy'brid (Gr. *monos*, one + *hybrida*, a hybrid). The offspring of parents that differ in one character.

Monosac'charid (Gr. *monos*, one + L. *saccharon*, sugar). Any of a number of sugars not decomposable into simpler sugars.

Morphol'ogy (Gr. *morphe*, form + *logos*, discussion). A branch of biology dealing with the form and structure of organisms.

Muco'sa (L. *mucus*, mucus or slime). A mucous membrane.

Muta'tion (L. *mutare*, to change). A sudden variation.

Mycel'ium (Gr. *myces*, mushroom). The threads which make up the body of a fungus.

My'elin (Gr. *myelos*, marrow). The fatty sheath of nerve fibers. The medullary sheath.

N

Na'res (L. *naris*, nostril). The nostrils or nasal openings.

Nau'plius (L. *nauplius*, shell-fish). A larval form of many crustaceans.

Nem'atocyst (Gr. *nema*, thread + *kystis*, sac). The nettle stinging cell of cœlenterata.

Nephrid'ium (Gr. *nephros*, kidney). Excretory organ of many invertebrates.

Neurilem'ma (Gr. *neuron*, nerve + *lemma*, skin). The delicate outer sheath of a nerve fiber.

Neurocœle (Gr. *neuron*, nerve + *koilos*, hollow). The cavity in the central nervous system

Neu'ron (Gr. *neuron*, nerve). A nerve cell and its processes.

No'tochord (Gr. *notos*, the back + *chorde*, a string). The primitive unsegmented axial skeleton of vertebrates.

O

Ol'igocene (Gr. *oligos*, small + *kainos*, new). A late period in geologic history.

Ommatid'inum (Gr. diminutive of *omma*, eye). One of the elements of which the compound eyes of arthropods are built up.

Oögo'nium (Gr. *oon*, egg + *gonos*, offspring). The female reproductive organ in lower plants like algæ.

Opalin'id (Gr. *opallios*, precious stone). A parasitic group of infusoria.

Ordovi'cian (L. *ordovices*, Celtic people in Wales). An early geologic period.

Organell'e (Gr. diminutive from *organon*, organ). Organ-like structures in protozoa but not composed of cells or tissues.

Orthogen'esis (Gr. *orthos*, straight + *genesis*, birth). Variation following some particular line and resulting in the evolution of some new type.

O'viduct (L. *ovum*, egg + *duco*, lead). The tube through which eggs leave the body.

Ov'um (L. *ovum*, egg). The sexual element produced by the female.

P

Palæontol'ogy (Gr. *palaios*, old + *onta*, existing things + *logos*, discussion). The science that deals with the life of past geological periods based on the study of fossil remains of organisms.

Palæozo'ic (Gr. *palaios*, old + *zoe*, life). A main division of geologic history.

Par'asite (Gr. *para*, beside + *sitos*, food). A dependent organism which gets its food directly from another organism, the host.

Parthenogen'esis (Gr. *parthenos*, maid + *genesis*, birth). Reproduction without fertilization.

Pentadac'tyl (Gr. *penta*, five + *daktylos*, finger). With five digits on the hand or foot.

Pep'sin (Gr. *pepsis*, cooking). A ferment which acts on protein.

Pep'tone (Gr. *peptos*, cooked). Digested protein.

Perider'mium (Gr. *peri*, around + *derma*, skin).

Phag'ocyte (Gr. *phagein*, to eat + *cytos*, sac). A white blood corpuscle.

Phosphores'cence (Gr. *phos*, light + *phero*, to bear). Production of light without sensible heat.

Photosyn'thesis (Gr. *light*, + *synthesis*, putting together). The process of making starch, peculiar to green plants.

Physiol'ogy (Gr. *physis*, nature + *logos*, a discussion). The study of life processes in animals.

Plas'ma (Gr. *plasma*, a thing formed). The liquid portion of the blood.

Podobran'chia (Gr. *pous*, foot + *bragchion*, gill). A gill attached to the basal segment of a thoracic limb.

Polydac'tyl (Gr. *polys*, many + *daktylos*, finger). Having several digits, especially more than usual.

Polymor'phism (Gr. *polys*, many + *morphe*, form). The existence of several kinds of individuals in a colony or community.

Pol'yp (Gr. *polys*, many + *pous*, foot). The individual animal found among cœlenterata, existing either alone or in colonies.

Polysac'charid (Gr. *polys*, many + L. *saccharon*, sugar). Any carbohydrate decomposable by hydrolysis into two or more simple molecules of carbohydrates.

Poste'rior (L. *posterus*, following). The hinder part of an organism; opposed to anterior.

Proneph'ros (Gr. *pro*, before + *nephros*, kidney). The first pair of kidneys to form in vertebrates and embryonic in all except certain fishes (cyclostomata).

Pronu'cleus (Gr. *pro*, before + L. *nucleus*, a kernel). Either of the two nuclei of a fertilized egg cell after maturation, but before segmentation.

Pro'phase (Gr. *pro*, before + *phasis*, appearance). A preparatory stage in mitosis.

Prosto'mium (Gr. *pro*, before + *stoma*, mouth). That portion of the body of certain worms and mollusks situated in front of the mouth.

Pro'tease. A protein enzyme.

Pro'toplasm (Gr. *protos*, first + *plasma*, molded form). The living substance of cells.

Protop'odite (Gr. *protos*, first + *pous*, foot). The basal portion of a typical limb of a crustacean.

Pro'toplast (Gr. *protos*, first + *plastos*, formed). The protoplasmic cell contents.

Pseudopo'dium (Gr. *pseudes*, false + *pons*, foot). A temporary protrusion on rectractile process of a cell.

Pylor'us (Gr. *pyloros*, gate-keeper). The opening between the stomach and intestine.

Pyre'noid (Gr. *pyren*, stone of a fruit + *eidos*, form). One of the colorless protein bodies found in the chromatophores of lower plants.

R

Ra'na (L. *rana*, a frog). A genus of frogs.

Reces'sive. (See Dominant.)

Regen'eration (L. *re*, again + *genero*, beget). The act of restoring a lost part by growing a new one.

S

Sap'rophyte (Gr. *sapros*, rotten + *phyton*, plant). A group of fungi which live on dead organic matter.

Sar'code (Gr. *sarx*, flesh + *eidos*, form). The protoplasm of the body of a venicellular animal. (*Du Jardine*, 1835.)

Sarcolem'ma (Gr. *sarx*, flesh + *lemma*, a skin). The thin transparent sheath of a striated muscle cell.

Sar'coplasm (Gr. *sarx*, flesh + *plasma*, a thing formed). The specialized cytoplasm of a muscle cell.

Schizomyce'tes (Gr. *schizein*, to split + *mykes*, fungus). The fission fungi or bacteria.

Sco'lex (Gr. *skolex*, worm). Head of a tapeworm.

Secre'tin (L. probably *secretio*, secreting). A substance extracted from the mucous membrane of the intestine and able to stimulate the pancreas to discharge its enzymes.

Sem'inal (L. *semen*, seed). Pertaining to or consisting of sperms.

Senes'cence (L. *senere*, to grow old). Old age.

So'ma (Gr. *soma*, body). The body cells of organisms as distinguished from the germ cells.

So'mite (Gr. *soma*, body). One of the segments of the body. (See Metamere.)

Sperm (Gr. *sperma*, seed). The male germ cell, same as spermatazoön.

Spermatoph'yta (Gr. *sperma*, seed + *phyton*, plant). The seed-bearing plants.

Sporan'gium (Gr. *spora*, a seed + *aggeion*, a receptacle). The case in which spores are produced.

Sporozo'ite (Gr. *spora*, seed + *zoe*, life). A stage in the life history of certain sporozoa.

Steap'sin (Gr. *stear*, tallow + *pepsis*, cooking). An enzyme found in the pancreas and assisting in the digestion of fats.

Ster'ile (L. *sterilis*, barren). Incapable of reproduction.

Symbio'sis (Gr. *syn*, together + *bios*, life). The habit of living together by two unlike organisms.

Syn'apse (Gr. *syn*, together + *aptein*, to fasten). The point of contact between two neurones.

Syncyt'ium (Gr. *syn*, together + *kytos*, a hollow vessel). A tissue or a structure containing many nuclei, but not divided into distinct cells by cell walls.

T

Taxon'omy (Gr. *taxis*, arrangement + *nomos*, law). The classification of organisms according to their natural relationships.

Te'liospore (Gr. *telos*, end + *spora*, a seed). One of the winter spores of certain fungi, such as rusts.

Tel'ophase (Gr. *telos*, end + *phasis*, appearance). The final stage in mitosis in which the entire cell divides and the new nuclei are formed.

Ter'tiary (L. *tertius*, third). One of the later geologic divisions; in the age of mammals.

Thalloph'yta (Gr. *thallos*, a young shoot + *phyton*, plant). A phylum of simple plants of very diverse habit and structure.

Thy'mus (Gr. *thymos*, a sacrifice). A ductless gland located near the heart.

Thy'roid (Gr. *thyreos*, large shield). A large ductless gland on the trachea below the larynx of higher vertebrates.

Tox'in (L. *toxicum*, poison). A poisonous substance formed by disease-producing bacteria.

Tra'chea (Gr. *tracheia*, windpipe). The air passage leading from the mouth to the lungs.

Tri'chocysts (Gr. *thrix*, hair + *kystis*, sac). Minute, dart-like rods in ectoplasm of paramecium.

Trypanoso'ma (Gr. *trypanon*, auger + *soma*, body). A parasitic protozoan infesting the blood of various animals, including man.

Tryp'sin (Gr. *tripsis*, a rubbing). An enzyme produced in the pancreas and acting on protein.

Tympan'ic (Gr. *tympanon*, drum). Membrane: A thin membrane which separates the middle ear from the outer.

Typh'losole (Gr. *typhlos*, blind + *solen*, channel). A longitudinal fold of the wall projecting into the cavity of the intestine in certain invertebrates.

U

Ure'dospore (L. *uredo*, a blight + Gr. *spora*, a seed). A summer spore of a rust fungus.

Ure'ter (Gr. *oureter*, from *ouron*, urine). A tube, one of two, leading from the kidney to the cloaca or to the bladder.

Urogen'ital (Gr. *ouron*, urine + L. *genitalis*, from *gigno*, beget). The organs common to the urinary and reproductive organs.

V

Vaccina'tion (L. *vacca*, cow). Inoculation with virus of cowpox as prevention against smallpox.

Ven'tral (L. *venter*, belly). Situated on the abdominal side or belly; opposed to dorsal.

Ven'tricle (L. *ventriculus*, a little belly). Any cavity of a hollow organ, especially one of the lower chambers of the heart

Vertebra'ta (L. *vertere*, to turn). The group of animals that have an axial skeleton of vertebræ terminating anteriorly in a skull.

Vi'rus (L. *virus*, poison). The element or principle that is the agent or medium for communicating infection.

Vi'tamin (L. *vita*, life). Certain substances in foods necessary to health.

Vo'mer (L. *vomer*, plough share). A bone of the skull.

Z

Zo'öid (Gr. *zoe*, life + *eidos*, like). An individual in a hydroid colony.

Zo'öspore (Gr. *zoe*, life + *spora*, seed). Motile spore.

Zy'gote (Gr. *zygotos*, yoked). Any spore formed by the conjugation of two gametes.

Zymotox'ic (Gr. *zyme*, leaven + L. *toxicum*, poison). One of the theories of germ disease.

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